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CHOLESTEROL CHANGES IN MONKEY MALARIA AND HÆMOGLOBINURIA.

BY

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[16th October, 1935.]

A LARGE number of workers have studied the cholesterol changes in the blood of humans suffering from malaria and blackwater fever. While the majority have recorded a hypocholesterinæmia, a few have found no material change (*vide* De Paulo Santos, 1916; Porak, 1918; Crespin and Zaky, 1919; Borel *et al.*, 1926; Whitmore and Roe, 1929; Ross, 1932; De Raymond, 1932; Nocht, 1929; Fairley and Bromfield, 1933; Feyte, 1932; Ott, 1932; Van den Branden and Nelis, 1933; Dufour, 1933; Robert, 1933; Wats and Das Gupta, 1934).

So far as blackwater fever in man is concerned, the inconclusive nature of the results may partly be accounted for by the fact that the blood samples taken from patients for estimation of cholesterol were obtained after the onset of the disease and not prior to it. As one cannot predict the onset of blackwater fever with any degree of certainty in man, it is not possible to determine the cholesterol value immediately prior to the onset of the condition, *i.e.*, in the pre-blackwater stage.

In experimental animals on the other hand, serial observations can be made without any difficulty. *Plasmodium knowlesi* causes in *Silenus rhesus* monkeys an acute and intense infection terminating in hæmoglobinuria and death within a short time, especially if the animals are splenectomised (Krishnan *et al.*, 1933, 1935). As far as we are aware, no one has studied in detail the cholesterol changes in monkeys during the course of plasmodial infection and hæmoglobinuria, or has attempted to interpret their significance. Studies on the cholesterol changes taking place in these animals from the commencement of infection to its termination, would not only show the fluctuations in blood cholesterol level in the different stages of infection and in the pre-hæmoglobinuric state, but would also indicate the rôle of cholesterol in phenomena such as hæmolysis, phagocytosis, cell proliferation and so on.

In some of our previous papers (Krishnan *et al.*, 1933, 1935), we pointed out with the help of cytological studies and splenectomy experiments in monkeys that the phagocytic cells of the reticulo-endothelial system played an important part in the ætiology and prevention of malarial hæmoglobinuria. In the course of these and other experiments the impression was gained that lipoid changes, especially those relating to the fatty acids, cholesterol and lipins, influenced markedly the behaviour of these cells. A reference to the available literature on the subject lent some support to this view. There was evidence to show that a relationship existed between the reticulo-endothelial system and lipoid metabolism, that the system was known to be concerned with the storage of cholesterol, and that proliferation of the cells of the system was often associated with hypercholesterinæmia. Furthermore our observations on the mechanism of phagocytosis (*vide* Krishnan, Chopra and Mukherjee, 1935) suggested that the degree of engulfment of particulate matter by the reticulo-endothelial cells was partly influenced by the concentration of lipoids (especially cholesterol) in the medium. It was therefore believed that a study, such as the present one, would help to verify the correctness of these tentative observations.

MATERIAL AND TECHNIQUE.

In this experiment *Silenus rhesus* monkeys were used, and *Plasmodium knowlesi* was inoculated to induce malaria. In some of the monkeys splenectomy was done to intensify the infection and bring on hæmoglobinuria. Samples of blood were obtained at all stages during the course of infection, *i.e.*, during the incubation period, during the parasitological period prior to hæmoglobinuria and death, and during and after administration of quinine, prior to natural recovery, latency and relapse. The amount of cholesterol in the whole blood was estimated according to Sackett's modification of Bloor's method (Sackett, 1925). The changes in the values of cholesterol under the different conditions were noted. In all 16 monkeys were used, and during the period of the experiment the animals were kept on a standard diet.

RESULTS OF INVESTIGATION.

BLOOD CHOLESTEROL IN NORMAL MONKEYS.

The total cholesterol in 23 samples of blood from normal *Silenus rhesus* monkeys was estimated. In some cases only one estimation was done while in others two or more were done at intervals of 3 to 7 days. The following values in mg. per 100 c.c. of blood were obtained :

143, 143, 150, 150, 157, 158, 158, 160, 160, 167, 167, 170, 170, 180, 188, 188. 190, 190, 200, 210, 210, 214, 214.

It will be seen from the figures arranged in the ascending order that the minimum was 143 mg., and maximum 214 mg., and the average about 177 mg., per cent. These figures are very similar to those of humans in whom the range of normality is generally accepted as being from 150 mg. to 190 mg. per cent for whole blood. The variation between individual monkeys was very much more marked than the variation in one and the same monkey examined at different times. It seemed as though each monkey had its own cholesterol level while on a standard diet, and that the level was more or less constant, fluctuating within a small range.

BLOOD CHOLESTEROL DURING THE INCUBATION PERIOD.

Fifteen samples of blood were obtained for cholesterol estimation during the incubation period. It was not possible to carry out the same number of estimations on all animals, because the incubation period varied from 4 to 10 days. In those, in which there occurred a rapid development of infection, only one estimation was done, while in others that showed a longer incubation period, 2 to 4 estimations were carried out. The following are the cholesterol values in mg. per cent, arranged in ascending order :

120, 126, 135, 140, 150, 158, 158, 176, 176, 188, 200, 200, 200, 214, 231.

It will be seen that the lowest value is 120 mg. per cent, the highest 231 mg. per cent, and the average 171·5 mg. This shows that during the incubation period there is practically no demonstrable change in the cholesterol level. In the case of one monkey in which four estimations were done during the incubation period, the cholesterol level was more or less constant throughout. In the case of another in which three estimations were done, there was a tendency for the cholesterol to drop down towards the end of the incubation period and prior to the appearance of parasites in the peripheral blood. This change was not seen frequently.

BLOOD CHOLESTEROL DURING THE PRIMARY PARASITOLOGICAL PERIOD.

In all 20 samples of blood were obtained for cholesterol estimation during the early stages of the primary parasitological period. The cholesterol values in mg. per cent are given below. Samples obtained during the later stages, when infection was intense, are not included here. They are presented in a separate group later in this paper.

107, 109, 111, 120, 125, 130, 130, 136, 143, 143, 150, 157, 157, 158, 167, 187, 188, 200, 222, 250.

From the above figures, it will be seen that the lowest value is 107, highest 250 and average 150. At first sight it cannot be said that there is any marked change. If, however, the variations from day to day during the progress of infection are considered in each monkey separately, there is some suggestion that the cholesterol value decreases when the parasite count increases rapidly. The data in Table I, which represent the values in seven monkeys when infection was moderately high, justify this conclusion. On the other hand, if the progress of infection is slow then the cholesterol value may be normal or may even show a slight increase. On the whole, the impression gained was that during the progress of infection great fluctuations in the level of cholesterol occur, and that there is a distinct tendency for the cholesterol to decrease as the infection becomes more and more intense.

BLOOD CHOLESTEROL DURING RELAPSE.

In all 25 estimations were made during relapse. The values obtained in mg. per cent are as follows :

94, 94, 97, 100, 107, 111, 120, 120, 125, 125, 130, 130, 150, 150, 158, 158, 166, 166, 166, 176, 176, 188, 200, 200, 200.

It will be seen that the lowest value is 94, highest 200 and the average 140. This shows that during relapse the cholesterol value is slightly lower than that during the primary infection. It was also noticed that with the progress of infection the cholesterol value showed a tendency to fall rapidly. The

cholesterol value in the later relapses was distinctly lower than that in the earlier ones. There was a clear indication that long standing chronic infection (both during latency and relapse) is associated with hypocholesterinæmia (*vide* Chart I).

BLOOD CHOLESTEROL DURING TREATMENT.

In all 16 attacks of malaria were treated with quinine. Of these 7 were primary attacks, and 9 relapses. Quinine was administered by injection and the cholesterol value determined daily till the disappearance of parasites from peripheral blood. The results are given in Tables I and II.

TABLE I.

Showing the changes in blood cholesterol after quinine injection in monkeys infected with P. knowlesi *(primary infection).*

(In mg. per cent.)

Prior to treatment.	DURING TREATMENT TILL DISAPPEARANCE OF PARASITES. 1st day.	2nd day	3rd day.	4th day.	5th day.
130	**200**	..	..	.	..
* **136**	136	143	120	**166**	..
120	107	107	**188**	..	..
* **125**	94	158	166	**176**	..
107	120	94	**150**	..	..
109	**176**	..			..
150	222	**300**		..	..

Average—125. Average highest level after quinine—194 55 per cent increase.

* Splenectomised animals.

TABLE II.

Showing the changes in blood cholesterol after quinine injection in monkeys infected with P. knowlesi *(relapse infection).*

(In mg. per cent.)

Prior to treatment	DURING TREATMENT. 1st day.	2nd day	3rd day.	4th day.	5th day	RESULTS.
97	**176**	..		..		Parasites absent in peripheral blood
130	166	**166**	.	.		" " " " "
111	107	**200**	176	..		" " " " "
107	**115**	..	..		..	" " " " "
150	150	136	136	**150**		" " " " "
123	120	**120**	..	..	..	" " " " "
166	166	**231**	180	180	..	Improved but low grade infection persisted.
150	166	**166**	150	166	..	" " " " "
176	166	**200**	170	166	..	" " " " "

Average—135. Average highest level after quinine—169. 25 per cent increase.

From Table I, it will be seen that the disappearance of the parasites from the peripheral blood after quinine injection was preceded by an increase in blood cholesterol. While the average value prior to treatment was only 125 mg. per cent, it rose to 194 mg. per cent after quinine injection and prior to recovery. A drop in cholesterol was noticed after all parasites had disappeared from the peripheral blood. During this study it was noticed that, while in non-splenectomised animals the maximum cholesterol value was reached after an average of three injections of quinine, in splenectomised animals it was only after 5 injections that the maximum level was reached. This suggests that the effects of splenectomy on the course of malarial infection and treatment may to some extent be due to the upsetting of the lipoid metabolism after splenectomy.

From Table II, it will be seen that the results of quinine injections on blood cholesterol in relapse infection are not as clear cut as are those in Table I. In 4 cases administration of quinine was followed by a rise in cholesterol and disappearance of parasites. In 2 cases parasites disappeared without any rise in cholesterol and in 3 cases a rise in cholesterol occurred without complete disappearance of parasites—a persistent low grade infection resulted. It may be pointed out here, that all the animals in this group were splenectomised animals. The absence of spleen may to some extent have been responsible for this divergence in the results. Taking the average experience in groups I and II, one may say that in the majority of cases administration of quinine resulted in an increase of cholesterol. This increase was of short duration and was soon followed by a drop in cholesterol which coincided with the disappearance of parasites from the peripheral blood. In a few cases, especially during relapses, disappearance of parasites from the peripheral blood after quinine was not associated with any such rise in cholesterol

BLOOD CHOLESTEROL DURING SPONTANEOUS RECOVERY.

Two monkeys that developed a moderately severe infection showed a distinct tendency to get rid of the parasites without any treatment. The cholesterol values of these two from day to day until recovery are given below in mg. per cent :

During intense infection	After				Remarks
	24 hrs.	48 hrs.	72 hrs.	96 hrs	
130	150	125	**185**	150	Parasites disappeared on 3rd day.
136	166	158	**214**	..	" " " " "

It will be seen that, prior to the disappearance of parasites spontaneously, the cholesterol level increased as in treated cases.

BLOOD CHOLESTEROL DURING LATENCY.

In all 40 estimations were done during 14 periods of latency. The results are presented below for each period and are subdivided into three groups, *i.e.*, early latency, mid-latency and end of latency.

TABLE III.

Blood cholesterol in mg. per cent during latency.

Early latency.	Mid-latency.	End of latency.
130	150	150
130	150	177
166	166	158
115	143	166
120	..	177
120	..	157
100	188	166
125	166	250
130	107	125
107	150	188
158	165	166
120	165	158
125	166	158
107	166	166
Average .. 125	156	170

It will be seen that the lowest figure is 100, the highest 250 and the average 150 mg. per cent. This at first sight suggests that during latency there is but slight lowering of the cholesterol value. If however we compare the figures at the commencement of latency with those at the end of latency and prior to relapse, it is found that in early latency the cholesterol level is definitely low, the average being 125 mg., and towards the end of latency, *i.e.*, prior to the onset of relapse, it is higher being 170. During relapse, when infection is progressively increasing, cholesterol again drops. If treatment be given then, the cholesterol value rises and recovery takes place. These changes, namely rise of cholesterol prior to relapse and prior to cure, were observed fairly constantly. The former was possibly associated with the growth and multiplication of the parasite and the stimulation of the cholesterogenetic centres, and the latter with cell proliferation (regeneration of both red and white cells). It is probable that cholesterol is needed during the progress of infection for some purpose possibly for building of new cells to replace the dead ones. This may explain why, after quinine administration and sudden checking of infection, there is a mobilisation and proliferation of both red and white cells as well as a rise in cholesterol. This is soon followed by a fall of cholesterol and restraint of infection. This we think is because hypocholesterinæmia is more favourable to phagocytosis than is hypercholesterinæmia, the latter condition being more favourable for cell proliferation than for phagocytosis.

BLOOD CHOLESTEROL IN HÆMOGLOBINURIA RESULTING FROM INTENSE INFECTION.

Intense infection developing in *Silenus rhesus* monkeys, if left untreated, generally ended in death with or without hæmoglobinuria. The cholesterol values of three monkeys, developing six attacks of hæmoglobinuria during the height of infection, are detailed below. Serial daily estimations, made from 48 hours prior to the onset of hæmoglobinuria up to the day of their death, are

recorded in Table IV. For comparison the cholesterol values of three other monkeys that died of intense infection without developing hæmoglobinuria are also given in Table V.

TABLE IV.

Blood cholesterol in haemoglobinuric monkeys.

(In mg. per cent.)

	48 hours prior to hæmoglobinuria.	Less than 24 hours prior to hæmoglobinuria.	24 hours or less after hæmoglobinuria.	RESULTS.
Hæmoglobinuric monkeys.	200	**175**	Died	Died of hæmoglobinuria.
	175	**90**	200	Recovered—no hæmoglobinuria.
	130	**90**	150	" " "
	143	**110**	180	" " "
	111	**80**	170	Died—no hæmoglobinuria.
	150	**150**	100	Died of hæmoglobinuria.

TABLE V.

Blood cholesterol in non-haemoglobinuric monkeys.

(In mg. per cent.)

	48 hours prior to death without hæmoglobinuria	Less than 24 hours prior to death without hæmoglobinuria.	RESULTS.	
Non-hæmoglobinuric monkeys.	**120**	**100**	Treated Recovered	No hæmoglobinuria.
	222	**150**	Died	" "
	214	**125**	Died	" "

From the above it will be seen that, in 4 out of 6 attacks of hæmoglobinuria, a marked and distinct drop in blood cholesterol was noticed 24 hours previous to the onset. In two however the values were normal. In the latter it is difficult to say if the values dropped down subsequent to the examination and shortly prior to the onset of hæmoglobinuria—the data show that this happened in one instance at least. It may therefore be stated that, while hypocholesterinæmia frequently precedes hæmoglobinuria, a normal cholesterol level may be met with prior to the condition. After hæmoglobinuria sets in there occurs a rise in blood cholesterol in most cases. This, if persistent, was generally associated with the disappearance of hæmoglobinuria but not of the parasites. It did not also prevent death. On the other hand, if the cholesterol rise failed to occur and the low value persisted, then the animal died without recovering from the hæmoglobinuria. This shows that hypercholesterinæmia may help to overcome hæmoglobinuria. In the non-hæmoglobinuric group, one out of 3 animals dying of severe infection showed a low cholesterol level. This

suggests that low cholesterol values do not in themselves determine the onset of hæmoglobinuria. Possibly other more important factors determine its onset, and hypocholesterinæmia is only one of the many factors concerned.

DISCUSSION.

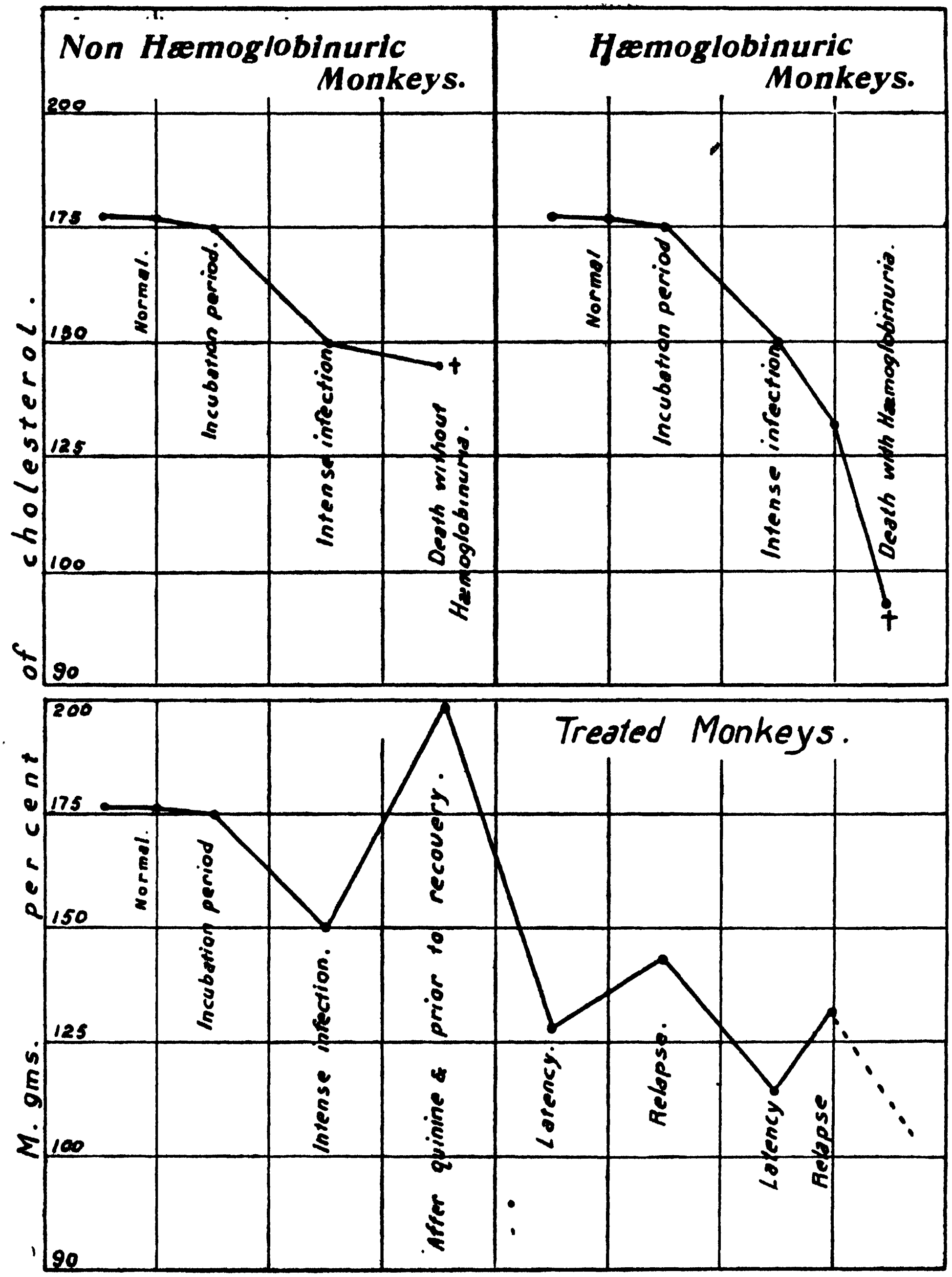
Although some workers have expressed the opinion that studies on blood cholesterol in certain infectious diseases have little or no practical value in malaria and hæmoglobinuria, the necessity for a detailed study of the lipoid changes and their significance cannot be over-emphasised. These substances form important constituents of the blood and tissue cells (red cells and reticulo-endothelial cells which are most concerned in malaria), and, therefore, it is not surprising to observe that they possibly play an important part in the alterations in these cells during the course of malarial infection. In the complicated equilibrated system, known as protoplasm, the lipoid substances represent the most labile types of compounds present; even slight variations in quantity or in chemical composition of these substances are capable of upsetting entirely the equilibrium of the protoplasm, and bringing about important changes in the behaviour of the cell. Whether it be such an ordinary commonplace phenomenon like oxidation, or one which is generally met with under abnormal conditions like hæmolysis, it may be argued that their rôle is a unique one which no other group of substances can possibly fulfil. A perusal of the results recorded in this article helps in a way to confirm this view. We have gained the impression that lipoid changes are associated with several important phenomena such as hæmolysis, phagocytosis and cell proliferation, and possibly also play a part, in some unknown way, in the development of acquired immunity to malaria. It would therefore be valuable to discuss the significance of some of the observed changes recorded in this article. For purposes of reference they are represented graphically in the chart.

DECREASE OF BLOOD CHOLESTEROL DURING INTENSE INFECTION AND ITS SIGNIFICANCE.

It is well known that blood cholesterol is influenced by factors such as diet, basal metabolism, infectious disease, hæmorrhage, anæmia and so on. Although it is probable that some of these factors may help to lower the cholesterol level during the malarial infection it appears to us necessary to take into account the failure of the cholesterogenetic mechanism as a possible factor in the lowering of cholesterol in malaria. In the early stages of malaria there is great fluctuation in the cholesterol level. This suggests that this substance is being used up or lost and more is being mobilised to meet the demand. Later when the infection gets intense the mobilisation fails (possibly due to failure of cholesterogenesis) and is followed by a sudden lowering of the blood cholesterol level and disastrous results. It is possible that during infection cholesterol is needed for various purposes, such as growth and multiplication of parasites, regeneration of red cells and monocytes and for transporting unsaturated fatty acids and other similar substances elaborated during infection. We have observed that a rise in cholesterol is associated with the onset of relapse and a fall with the onset of latency. This suggests that cholesterol influences parasite growth or is associated with it. Likewise the lowering of the cholesterol level has been observed to be associated with a lowering of the reticulocyte and

CHART I.

Cholesterol changes in monkey malaria and hæmoglobinuria.



monocyte counts, and an increase with the appearance of large numbers of these cells. The rise in the proportion of cholesterol esters to total cholesterol that occurs during infection, indicates that cholesterol is helping in the transport of unsaturated fatty acids and other substances which are being formed in excess of normal. If the above assumptions are correct then the rôle of cholesterol may be claimed to be of importance in malaria.

INCREASE OF BLOOD CHOLESTEROL AFTER QUININE ADMINISTRATION AND PRIOR TO RECOVERY, AND ITS SIGNIFICANCE.

The observation that in malaria with the improvement in the clinical condition a coincident increase in blood cholesterol occurs, is by no means peculiar to the disease. Valois is reported (*vide* Levinson, 1931) to have made similar observations in tuberculosis. The studies of Jolly and Mondelange (*vide* Levinson, 1931) also indicate that in typhoid and paratyphoid fevers the cholesterol content, which is low during the acute febrile stage, rises progressively with the recovery of the patient. Krishnan, Pai and Bose (1936) have found that the hypocholesterinæmia of kala-azar cases is converted into hypercholesterinæmia after specific treatment and during recovery. In pernicious anæmia there is hypocholesterinæmia, but after liver therapy there is a rise in cholesterol value and this is associated with the regeneration of red cells, the appearance of reticulocytes and recovery from the disease. In malaria we have shown that, after quinine treatment, blood cholesterol rises prior to recovery and is associated with increase in the reticulocyte and reticulo-endothelial cell counts. It is possible that *cholesterol plays an important part in recovery from malaria through stimulation of cell proliferation.* The work in connection with cancer (Luden, 1918-19) has demonstrated that cholesterol promotes cell multiplication. Hypercholesterinæmia may therefore be considered as being favourable for regeneration of red cells and macrophages which are needed for the cure of malaria. Quinine by bringing about this change helps in the recovery from malaria. When the drug fails to bring about a very high cholesterol response, as in the relapse cases, the proliferation of red cells is not quite as marked as in the primary attacks. In animals that recover from malaria spontaneously without quinine, a similar rise in cholesterol occurs and is associated with increase of red cells and macrophages.

RÔLE OF CHOLESTEROL IN HÆMOLYSIS AND HÆMOGLOBINURIA.

Although the factors concerned in hæmolysis are not fully understood it is being increasingly recognised that, through a proper understanding of the properties and behaviour of lipoids, a satisfactory explanation of the mechanism of hæmolysis can be obtained. Even the simplest picture of the process of hæmolysis would be inadequate if it did not refer to the general properties and functions of the cell membrane, and here again the lipoid substances have to be studied and considered from an entirely new point of view. It is generally believed that cholesterol is responsible for causing the cohesion of the molecules on the cell-wall and preventing the escape of hæmoglobin from within the red cell. This view is supported by the fact that, when cholesterol is diverted away from the red cell-wall experimentally through the introduction of suitable chemical substances, permeability of the cell-wall increases and hæmolysis occurs. It has also been shown that substances which

cause hæmolysis are mostly those that engage cholesterol, and that when the concentration of cholesterol is increased experimentally the hæmolytic action of substances such as soaps and fatty acids is counteracted. The observations made during the present investigation indicate that a condition of hypocholesterinæmia exists in the pre-hæmoglobinuric state, that a rise in cholesterol occurs after hæmoglobinuria has set in, and that this rise is invariably followed by the disappearance of the condition. When the rise fails to occur, the animal dies in the hæmoglobinuric state. Therefore, it may be concluded that, while low cholesterol is favourable for hæmolysis and hæmoglobinuria, normal or high cholesterol has an inhibiting influence on both these, in most cases.

SUMMARY AND CONCLUSIONS.

The normal blood cholesterol values in *Silenus rhesus* monkeys varied from 143 to 214 mg. per cent and the average was 177 mg. per cent.

After infection with *Plasmodium knowlesi* and during the incubation period, no appreciable change was noticed. The value varied from 120 to 213 mg. per cent and the average was 171·5 mg. per cent.

During the primary parasitological period of infection, great fluctuations occurred in the cholesterol level. The value varied from 107 to 250 mg. per cent and the average was 150 mg. per cent. The impression gained was that towards the end of the parasitological period, when the infection was intense there was a distinct tendency for the cholesterol to diminish in the majority of instances. The values at this stage varied from 107 to 150 mg. per cent and the average was 125 mg. per cent.

After quinine treatment and prior to recovery, the cholesterol value generally rose up to normal or slightly higher than normal; while the average value prior to quinine was 125 mg. per cent it was 194 mg. per cent, after quinine. This represents an average rise of 55 per cent.

In latency cholesterol values were low but they rose prior to the occurrence of relapse. The average value early in latency was 125 mg. per cent, but prior to onset of relapse it rose to 170 mg. per cent. Increase of cholesterol invariably preceded the onset of relapse.

During relapse, when the intensity of infection was increasing, the cholesterol value fell markedly unless treatment was given. The value during relapse varied between 97 and 176 mg. and the average was 135 mg. per cent. After treatment the average rose to 169 mg. per cent. This represents a rise of 25 per cent.

During relapse the cholesterol value was lower than during the primary infection. In the later relapses the values were lower than in the earlier relapses. In chronic long standing malaria a condition of hypocholesterinæmia was seen.

Twenty-four hours prior to the onset of hæmoglobinuria a condition of hypocholesterinæmia was noticed in 4 out of 6 attacks, the cholesterol values being 80, 90, 90, 110 mg. per cent. In the other two attacks the values were normal (150 and 175 mg.). This shows that hæmoglobinuria may occur both when the cholesterol value is normal or subnormal.

In 2 out of 3 monkeys that did not develop hæmoglobinuria despite an intense infection, a condition of hypocholesterinæmia occurred (the values were

100 and 125 mg. per cent). Hypocholesterinæmia during intense infection was not always followed by hæmoglobinuria.

A rise in cholesterol to or above normal values, or a persistence of normal values after occurrence of hæmoglobinuria, invariably resulted in the disappearance of the condition. The values obtained when hæmoglobinuria disappeared were 100, 150, 170, 180 and 200. Cholesterol is capable of exerting an inhibiting influence on hæmolysis and hæmoglobinuria resulting from intense malarial infection in monkeys.

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Records of the Malaria Survey of India, 6, 1, March, 1936.

MALARIA CONTROL BY SUBSOIL DRAINAGE AT WALTAIR.

BY

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[26th October, 1935.]

THE Railway Colony at Waltair, the civil station of Vizagapatam, is situated on a gently sloping strip of land between a spur of the Eastern Ghats and the backwater which is in process of conversion into the new harbour of Vizagapatam. The railway station is a very important one, being the junction point between the Bengal-Nagpur and the Madras and Southern Mahratta Railways, with a large locomotive shed, wagon-sorting sidings, etc. With the growth of the Port, more and more staff, to deal with the increasing traffic, are being posted to the station. The administration of the latter, including medical aid, is in the hands of the Bengal-Nagpur Railway.

The Railway Colony area is traversed at its centre by a hill stream, the Yarra Gedda, here running in a sandy bed between artificially-raised banks, as it is liable to flood the yard when in spate. There are also large areas of seepage, which is usually not in sufficient amount to form streams, but stands clear and fresh among grassy vegetation. At the east (town) end of the colony are some borrow-pits, and, close to the railway boundary, tanks of the usual type seen on the Indian plains.

On the south, the land gradually shades off into the mud of the backwater, into which the Yarra Gedda discharges. This backwater is saline. Portions of it are under tidal influence, other portions appear to be scarcely affected by it. In any case, the tidal range is very small, probably not exceeding two feet.

Between the railway land and the backwater runs a municipal road upon an embankment. This adds greatly to the drainage problem, because the culverts in this embankment are much too high and are partially choked, and because the road is maintained by the periodical excavation of borrow-pits along its margins. There is a rice-field area north of the railway boundary, close to the bungalows of the European staff.

Though malaria was never hyperendemic, that there was more than enough of it to justify the protection of such an important industrial community, is shown by the figures in Tables I and II.

TABLE I.

Malaria incidence, Railway Colony, Waltair.

Year.	Population.	Cases.	Incidence, per cent.	Days of work lost.	Days lost per employee.	REMARKS.
1925	817	363	44·4	614	4·26	
1926	817	425	52·0	355	2·47	
1927	698	75	10·7	96	0·67	Railway control started.
1928	704	14	2·0	82	0·57	Harbour control started.
1929	905	29	3·2	145	0·64	
1930	1,232	24	1·9	93	0·34	Gopalapatnam control started.
1931	1,208	15	1·2	55	0·18	
1932	1,343	11	0·9	41	0·15	First year of serious municipal control work.
1933	1,309	15	1·1	82	0·31	Yarra Gedda control extended.
1934	1,488	2	0·1	4	0·01	

TABLE II.

Spleen indices within present Waltair Railway Colony protection.

Locality.	April 1926.*	September 1932.*	April 1935.†
Colony	11·1	0·5	0·0
Gyanapuram village ..	21·0	..	1·0
Dondaparti village ..	56·7	..	0·0

* Children at random.
† Schools.

The peak of the malaria curve occurred in September or October of each year.

The area was surveyed in April and again in November 1926. The Anopheline fauna found was :—

A. subpictus Grassi.
A. vagus Dönitz.
A. culicifacies Giles.
A. varuna Iyengar.
A. aconitus Dönitz.
A. annularis v. d. Wulp.
A. pallidus Theobald.

No dissections were made, but the carriers are undoubtedly *culicifacies* and *varuna*.

Protection was started in 1927 by oiling, the seepages being collected by open earth drains. A good deal of cinder-filling of water-holding depressions and small borrow-pits (some 300 wagon loads, at a cost of Rs. 500) was done as soon as possible after work was initiated. In 1928 the harbour construction started seriously, *pari passu* with protection work over their area, as so favourably commented on by the Malaria Commission of the League of Nations (1930), and more fully described by Satyanarayana (1934). The Port area interlocks with the railway area near the backwater. In 1930 the signal cabin at Gopalapatnam, the actual point of divergence of the two railways towards Madras and Calcutta respectively, about four miles west of Waltair, was brought under protection. This was done not only on account of its exceeding malariousness affecting the health of the staff stationed there*, but also on account of infections picked up there by men working trains which were delayed at the junction by signals. In 1932 the Vizagapatam municipality at last yielded to pressure, which had been continuously exerted by the local Malaria Advisory Committee, and initiated serious anti-malarial operations, which included municipal land co-terminous with railway and port land south and east of the station. In 1933 the District Board, hitherto recalcitrantly supine, agreed to reimburse the railway for controlling the Yarra Gedda in part of its course in their area. The railway had, up till then, been oiling a length of this stream well outside its own limits, but the District Board's contribution enabled a further length upstream of this to be undertaken. This largely did away with the washing-in of larvæ from the upper reaches of the stream, which had hitherto been a considerable nuisance in control work.

The rice fields mentioned earlier, some thirty acres in extent, were brought under paris-green control in August 1933†. Sporadically there was much opposition to this from the ryots (peasants), who alleged that the powder damaged their crops. This culminated in July 1934 in absolute refusal to allow dusting. In consequence the weekly *culicifacies* catch in the Loco. Foreman's bungalow, the nearest of all the quarters to the rice fields, which had been nil for some months previously, rapidly rose until, a month after stoppage of dusting, it amounted to 10 ♂♂ 40 ♀♀. It took a month to reduce it again to single figures, after the Collector had taken action under the Madras Local Boards Act and sent the Tahsildar to enforce his authority and be present during dusting. Fortunately this area has now been bought up by a speculative builder for an extension of the town.

* The spleen index of Buchirazupalem village, within a quarter mile of the Signal Cabin, was 62 per cent in April 1926. It was 3·5 per cent in 1933. There has not been a single case of malaria since February 1933 among the 27 staff and dependants living within the Gopalapatnam protection area.

† On survey this area had been found to breed *A. subpictus* and *A. vagus* only, and so no control measures were in force. As the result of some few extra cases of malaria in 1933, this area was re-examined, and *A. culicifacies* and *A. varuna* were then found breeding in these fields and their irrigation wells. This paddy—owing to water shortage—is not cultivated every year. The carrier species of *Anopheles* only appear when rainfall is sufficiently heavy to permit of rice cultivation.

When these forms of protection were in full working order, the lengths under weekly oiling were:—

Seepage drains running almost perennially	..	10,150 ft.
Sullage drains (oiled for mosquito nuisance)	..	2,000 „
Drains only running from August to November	..	11,500 „
Streams, partly perennial, partly drying up	..	13,600 „
Total	..	37,250 ft.

The annual consumption of oil is shown in Table III.

TABLE III.

Consumption and cost of oil used at Waltair control.

Year.		Gallons.	Cost, Rs.	REMARKS.
1929-30	..	1,831	801	
1930-31	..	1,890	827	
1931-32	..	1,640	718	
1932-33	..	1,270	556	
1933-34	.	1,580	691	Yarra Gedda extension of protection.
1934-35	..	1,450	634	

At this period the malaria staff consisted of one Inspector (also in charge of Gopalapatnam junction), one mate and nine coolies. The pay of this staff (deducting the proportion of the pay of the Inspector debitable to the other protection) amounted to Rs. 2,422 annually.

Early in 1932 the conversion of the open drains into subsoil drains was commenced. The work was undertaken by the malaria gang in the dry seasons only, and so was not completed until 1935. The general financial stringency made this period most inopportune for demands on capital account, which the provision of a system of pipe drainage would have involved. For this reason recourse was had to stone drains built with material available on the slopes of the hills behind railway land. For this work some extra, casual labour, and bullock-carts and their drivers were engaged, the cost being met from current revenue accounts.

The work was commenced by lowering the depth of the drains to three feet* (Plate I, fig. 1), flat-sided stones were laid to form a tunnel, over which smaller stones, gradually decreasing to the size of road metal, were placed. The whole was topped off with earth, into which grass was dibbled. An open storm-water channel, six inches or more deep, is left above the subsoil drain.

* The drains in the last area to be subsoiled cannot even be taken to this depth, but only to 18 to 24 inches. In this area the individual drains are short, and, being protected by the railway track close above them, will not get the full force of flood scour. How these drains will fare in future remains to be seen.

Plate I.

Fig 1

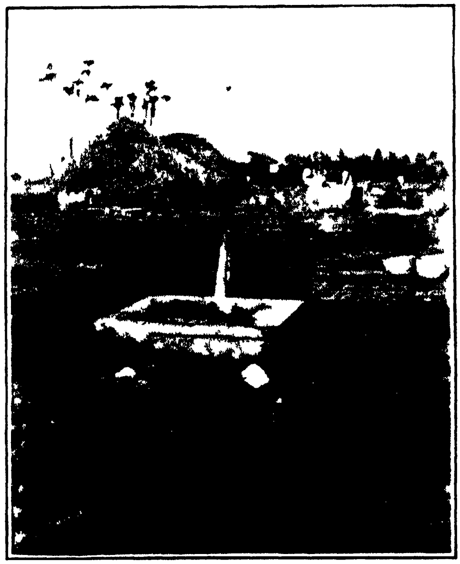


Fig 4

Fig 2

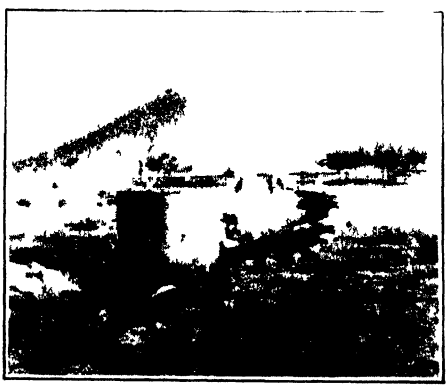


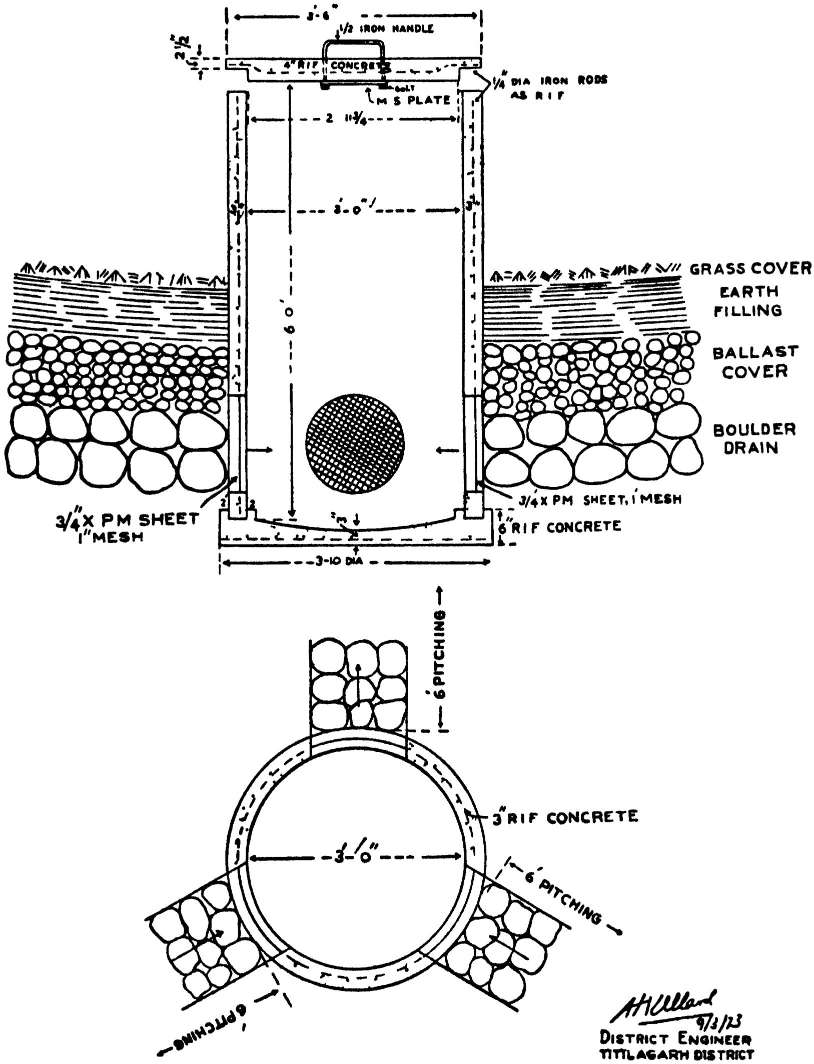
Fig 3

Fig 5

Fig 1—Subsoil drain under construction Fig 2—End of subsoil-drained length Fig 3—Inspection pit and silt trap combined at junction of subsoil drains Fig 4—Grease trap in drain from dhoby colony, continued as subsoil drain Fig 5—A former open seepage catch-drain subsoiled without straightening of its course

Diagram showing details of combined junction, and inspection pit and silt trap.

Silt trap at the junction of sub-soil water drains at Waltair. Scale $\frac{3}{4}'' = 1'$.



At the ends of the drain the stone work is set in cement concrete, with a piece of expanded metal across the orifice (Plate I, fig. 2). Where drains make junctions, a modification of Scharff's Penang-type 'inspection pit *cum* silt trap' is installed (Plate I, fig. 3; and Diagram). The modification mainly consists in 'windows' of expanded metal placed in the walls of the pit, to hold the stones of the drain in position*. The lids of the pits are so heavy that they can only be lifted by two men with a wooden bar passed through steel handles, thus preventing theft and the throwing-in of rubbish. As the subsoiled lengths approach the flat land above the backwater, they come too near the surface for the subsoiling to continue (the available depth being governed by the culverts on the road referred to on page 13). Their final lengths have still to be left open and oiled.

Sullage water from a dhoby colony and some quarters is taken to the drains after being first cleared in cement grease traps (Plate I, fig. 4).

The first drains to be subsoiled were simply converted from the old open seepage drains and curved about following irregularities in the ground (Plate I, fig. 5). Their junctions were not provided with silt pits. Later subsoil work has made use of freshly-cut, straight drains, from the excavated earth of which the old meandering drains have been filled up. These drains have silt pits. As regards efficiency, the later improvements have so far shown no particular advantages over earlier work.

One case of scouring has occurred, after very heavy rain, but it was a simple matter to relay the damaged length with the ordinary gang in a few days. This is an advantage over pipe drains, which in any case are unsafe at so shallow a depth as three feet. The lines of the drains are indicated by whitewashed stones, to be seen in several of the figures reproduced This is cheaper, if not so elegant, as the Malayan method illustrated by Stewart (1931).

Subsoil drainage has been done for a distance of 6,745 feet, *i.e.*, 67 per cent of the total, perennially running, seepage drains. In addition, 425 feet of open shallow outlet from one drain has been set in stone and cement at a cost of Rs. 90, to connect with other 'pukka' sullage drainage maintained by the Engineering Department

Cost.

	Rs.
6,745 feet of subsoiling	480
6 junctions silt pits	215
Total Rs. ..	695

In the above figures no account has been taken of the cost of the labour of the malaria gang, employed on this work in the dry weather; so, for comparison's sake, it will be fairer to add Rs. 1,008, the cost of this, to the above figures, making the total cost for 6,745 feet subsoiled, Rs. 1,703, which works out at 4 annas per running foot.

* The pits are cast in reinforced concrete, the angles of the entrance and exit windows being adjustable in a single mould, from which a pit to suit any angles of junction and exit can be cast.

Scharff (1935) gives 29·5 Malayan cents as the 'all-in per foot run' cost of laying a six-inch pipe line at four feet. This represents approximately Re. 0-8-2 in Indian currency. But in India such pipes are not available, and they would have to be imported from Singapore, and skilled labour, not coolies, would have to be taught how to lay them. Thus the saving of stone drains over pipes is really much more than the Rs. 1,740 the above figures indicate.

As regards revenue-account savings due to the installation of these subsoil drains: (*i*) in spite of the 1933 extension of the oiling, which would otherwise certainly have involved an extra coolie in the malaria gang, this has been avoided, and (*ii*) the gang itself has not only been reduced by two, but in the wet months one of the Waltair gang is transferred to Gopalapatnam, so the total saving in labour amounts to 3½ coolies a day over the year, equalling Rs. 588.

Before the subsoiling was introduced the average cost of oil was Rs. 814 per annum. From Table III it will be seen that the Yarra Gedda extension costs Rs. 135 for oil each year, which must be deducted from the total oil expenditure in 1934-35, the last figure available, though some short lengths were not subsoiled until the close of that financial year. The saving of oil in the subsoiled area thus amounts to Rs. 315 annually. Adding the labour saving to this, the total annual saving is Rs. 903. Thus the drains have paid for their cost to the malaria budget in eight months, and in under two years to the railway finances as a whole. Further, their installation has done away with the continuous repairs to the damage caused by cattle and buffaloes that still goes on in the open sections. It also prevents any fear that a single round of defective oiling may allow of an increase of adult carriers*.

Finally, the completion of the subsoil work has so reduced the work of the malaria inspector that it has been possible to place him in charge of a third protection, which formerly had its own supervising staff.

There must be many parts of submontane and peninsular India where stone is easily available and where many of the breeding grounds are suitable for this form of permanent anti-malaria measures. It is being largely installed on the malaria-protection works of this railway, wherever suitable conditions exist.

In conclusion, I wish to thank M. R. Ry. V. Venkata Rao, A.R.San.I., Malaria Inspector, Waltair Area, who from start to finish has carried out the whole of the protection works described in this paper, and Mr. F. Tubby, B.Sc., A.M.I.C.E., A.C.G.I., Assistant Engineer, Vizianagram Subdivision, for his aid in designing for this Department the mould for making the junction pits.

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* Comparison of the figures given in Table I with the Loco. Foreman's bungalow catch, recorded on p. 15, suggests that the gametocyte rate is now so low that a temporary Anopheline outburst is here not followed by malaria, as it would be with a less successful protection.

Records of the Malaria Survey of India, 6, 1, March, 1936.

TEBETREN TREATMENT IN MALARIA.

BY

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[5th November, 1935.]

INTRODUCTORY.

THIS short paper records a small series of cases of malaria treated with tebetren during the months of July and August 1934, in the tea-garden hospitals under my supervision. For comparison some notes are also given on treatment with quinine and with atebrin-plasmoquine.

TEBETREN*.

This is designated by the manufacturers as a combination of acridine and quinine derivatives with a derivative of cholic acid. They state that, on account of its very minute dissociation constant, it is superior to all other preparations in the chemotherapy of malaria. It is said to be split up in the body merely by the reaction of the blood. It is also stated to be 50 per cent less toxic than quinine. The manufacturers claim that tebetren remains in the blood stream in active form for a considerably longer time than any other anti-malarial remedy. Tebetren is also said not to affect the liver.

Tebetren is stated to be a mixture of hydroquinine, acriflavine and bile salts or acids. The amount of acriflavine is relatively small. The amount of hydroquinine is high, probably over 80 per cent of the total. The drug is issued in tablets of 3 grains each.

DOSAGE GIVEN.

The dosage recommended by the manufacturers is 3 tablets, three times a day for six days for adults, and for children ½ of one tablet according to age.

* The manufacturers are Howards & Sons, Ltd., Ilford, London, for Chemopharm, Ltd., 58, Victoria Street, London, S.W., who kindly supplied the drug to me for trial, through their Calcutta agent, Mr. Ralph Paxton.

The dosage employed in the present small series of cases, was 42 tablets over a period of 6 or 7 days. This dosage was suggested by Barrowman (1933) as a satisfactory modification of the original procedure. The doses were distributed as follow :—First two days, 3 tablets 3 times a day, and then 2 tablets 3 times a day for the remaining 4 days. Some modification in dosage was used in cases which showed 'toxic' symptoms, dosage being modified as shown below, but in all cases the total dosage was 42 tablets.

The distribution of dosage was as follows :—

3 tablets thrice daily for 2 days .. 2 tablets thrice daily for 4 days ..	9 cases.
2 tablets thrice daily for 7 days ..	6 cases.
3 tablets thrice daily for 1 day .. 2 tablets thrice daily for 5 days .. 1 tablet thrice daily for 1 day ..	6 cases.
Total ..	21 cases.

Only adults were treated.

Twenty-one cases were treated in all, the types of infection being as follows :—

Malignant tertian	16
Benign tertian	4
Mixed M.T.* and B.T.* . ..	1
Total ..	21

Table I shows the results of the blood examinations. These were carried out daily for 7 days in all cases and in some over a longer period. Two cases of typical 'clinical malaria' were negative at blood examination on the first day but showed infection subsequently during treatment.

It will be seen that, of the sixteen M. T. cases, 10 became negative on the second day and all were negative on the sixth day. Of the four B. T. cases, 3 were negative on the second day of treatment and all were negative on the sixth day. The single case of mixed infection was negative for both M. T. and B. T. on the third day.

TOXIC EFFECTS PRODUCED BY TEBETREN.

It is difficult to assess the true position of any drug used in the chemotherapy of malaria in producing toxic effects, as the disease itself can cause most of the symptoms which are generally included in the so called 'toxic' group. Headache, giddiness and gastric disturbance are all symptoms of untreated malaria.

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* In this paper the contraction 'M. T.' is used to denote 'malignant tertian' infections, and 'B. T.' 'benign tertian' ones.

Table I.

Blood examination after the commencement of treatment.

No. of case.	Type of infections.	1st day.	2	3	4	5	6	7	8	9	10	11	12	13	14
1	M.T. rings ..	+	–	–	–	–	–	–							
2	M.T. rings ..	+	+	+	+	–	–	–							
3	M.T. rings ..	+	–	–	–	–	–								
4	B. T. rings ..	+	–	–	–	–	–								
5	M.T. rings ..	–	–	–	–	–	–	–							
6	M. T. trophozoites.	+	+	–	–	–	–	–	–	–	–				
7	M. T. trophozoites.	–	–	–	–	+	–	–	–						
8	M.T. rings ..	+	–	+	–	–	–	–	–						
9	M.T. rings ..	+	–	–	–	–	–								
10	M.T. rings ..	+	–	–	–	–	–	–							
11	M.T. rings ..	+	+	–	–	–	–	–							
12	M.T. rings ..	+	–	–	–	–	–	–							
13	B. T. rings ..		+	+	+	+	–	–	–	–	–	–			
14	B. T. trophozoites.	+	–	–	–	–	–	–	–	–	–	–	–		
15	M.T. rings ..	+	+	+	–	–	–	–	–	–	–	–	–	–	–
16	M.T. rings ..	+	–	–	–	–	–	–	–	–	–	–	–	–	–
17	M.T. rings ..	+	+	–	–	–	–	–	–	–	–	–	–	–	
18	M.T. rings ..	+	–	–	–	–	–	–							
19	M. T. trophozoites.	+	–	–	–	–	–								
20	B. T. rings and schizonts.	+	–	–	–	–	–	–							
21	M. T. and B. T. rings.	+	+ B. T. rings.	–	–	–	–	–							

Table II gives the main effects noted in the present series :—

Table II.

Giddiness, insomnia and delirium	2 cases
Giddiness and insomnia	2 cases
Giddiness and delirium	1 case
Tinnitus, dimness of vision and convulsions	1 case
No particular symptoms	15 cases
Total . ..	21 cases

Of these symptoms, which can be attributed directly to tebetren ?

Giddiness, tinnitus and mild delirium are symptoms of ordinary malaria and cannot be catalogued as directly due to tebetren. On the other hand, the

insomnia noted in four cases was more marked than is usual in malaria cases in this district. Delirium in one case was also much more pronounced than usual. This patient, who suffered also from intense thirst, ran out of hospital. Delirium lasted for 24 hours and occurred on the third day, after the temperature had dropped to normal the previous day. The highest temperature during delirium was 99°F., and the infection was due to *P. falciparum.*

It seems reasonable to attribute, at least in some degree, the more definite insomnia and the marked delirium, to the action of tebetren. Fifteen cases exhibited no special symptoms. In no case were there any after-effects from treatment.

RELAPSE RATE.

In judging relapse rates, due stress must be laid on the possibility of reinfection. Malaria control by dense shading, oiling, and dusting with paris green has been carried out on these gardens since 1931 with marked success. The incidence of malaria is low, but the possibilities of reinfection are not entirely eliminated. It is better, therefore, to term the recurrence of malaria in these cases as a 'relapse-reinfection rate'. Of the 21 cases treated with tebetren, three developed malaria within a period of six months after cessation of treatment. This gives a 'relapse-reinfection' rate of 14·3 per cent.

Formerly quinine was used almost exclusively in this practice, and the relapse-reinfection rate was approximately 40 per cent in all types of malaria. Quinine treatment was carried out in these cases by different methods including :—Sinton's method; a long quinine course of 3 months' treatment beginning with 30 grains for 3 days and tailing off to 10 grains twice weekly during the last six weeks, a total of 400 grains of quinine in all; and the shorter course of 20 grains daily for 10 days was also used. The net result from all methods of treatment was approximately the same. The salt used was quinine bihydrochloride given during the active period of fever and subsequently quinine sulphate in solution.

ATEBRIN AND PLASMOQUINE.

These drugs have been used during the last 4 years in replacement of quinine. The original treatment was atebrin 0·1 gramme thrice daily with plasmoquine 0·02 gramme daily, for 5 days, or with a modified course of plasmoquine as indicated by the condition of the case. The results were considerably better than with quinine, but symptoms of plasmoquine intolerance were observed in a small number of cases. It is not proposed to go into details of this type of treatment here, except to note that at present the treatment with atebrin and plasmoquine is being used in modified form. The present dosage used is atebrin, 0·1 gm. thrice daily for 5 days combined with plasmoquine 0·0033 or 0·005 gm. in one tablet. These smaller doses of plasmoquine are well tolerated and symptoms of toxic origin are very rarely observed. This treatment has been further modified by the use of atebrin and plasmoquine 'dragées' in the same dosages. No toxic symptoms have followed in the small series of cases already treated with the dragées.

Twenty-nine cases have been treated with the modified atebrin-plasmoquine therapy and of these four showed a recurrence of malaria within six months. Table III shows the comparative results :—

TABLE III.

Comparison of results.

Treatment.	Number of cases treated.	Recurrence	Relapse-reinfection rate (Per cent)
Quinine . ..	200	80	40·0
Tebetren ..	21	3	14·3
Atebrin-plasmoquine ..	29	4	13·7

Whilst the quinine 'relapse-reinfection rate' may be taken as approximately correct, the series being sufficiently large to compensate for error, it must not be inferred that the 'relapse-reinfection rates' with tebetren and atebrin-plasmoquine are conclusive. The number of cases treated in both series is too small to permit definite deductions being made. It is evident that one case might be treated with atebrin-plasmoquine and show no subsequent malaria and yet the conclusion that the cure rate was 100 per cent for this drug would be entirely misleading. A much larger number of cases must be included in the two latter series before the comparison can be strictly accurate To emphasise this important point, I quote here the relapse rates of quinine, atebrin and tebetren treatments as reported by other observers :—

Green (1934) states that he treated 100 cases of malaria with tebetren and compared such cases with others treated with quinine and others again with atebrin. He gives the 'general relapse rate' after atebrin as 4 per cent: after quinine, 38 per cent: and after tebetren, 49 per cent.

Barrowman (1933) states that, in 50 cases treated with tebetren, none relapsed over a period of six months, and again that of 26 cases treated with 42 tablets, one case relapsed in the third month.

It is manifestly clear that relapse rates, running from nil in Barrowman's cases to 14 3 in my series and 49 per cent in Green's series, show that there is a grave defect in regarding percentages, and especially percentages of small series of cases treated with any particular drug, as definite and final. Until medical men adopt strict statistical methods, little can be deduced from such incomplete data.

The duration of fever is given in Table IV and is calculated on the number of hours of fever following commencement of treatment. The averages only are given and fractions of hours are not shown. The dosages, used in each case, have already been indicated.

TABLE IV.

Comparative table of duration of fever.

Treatment.	AVERAGE DURATION OF FEVER IN HOURS.	
	M.T.	B.T.
Quinine salts ..	54 hours	40 hours
Tebetren	43 „	62 „
Atebrin-plasmoquine .	33 „	72 „

From Table IV, it will be evident that tebetren is appreciably better than quinine in malignant tertian malaria but has no advantage in benign tertian. Atebrin-plasmoquine compares favourably with both quinine and tebetren in malignant tertian malaria but is slightly less rapid in action in benign tertian.

EXCRETION OF TEBETREN IN THE URINE.

Examination of urine by a modified Mayer's reagent containing acetic acid as suggested by Field and Kandiah (1935) showed presence of tebetren during treatment, but tebetren was not found in the urine longer than four days after treatment ceased. The drug is evidently not cumulative, at least in the dosage used in this series.

RELATIVE COST OF TEBETREN TREATMENT.

This can only be given approximately as the quinine course is variable and the table shown is based on a dosage of 300 grains of quinine bihydrochloride.

The price of tebetren is stated by the manufacturers to be Rs. 40 per 1,000 tablets, so that a dose of 42 tablets costs approximately Re. 1-11 per treatment. The cost of atebrin-plasmoquine in dosage of 0 1 gm. and 0·0033 gm. respectively, thrice daily for 5 days, is approximately Re. 1-7.

The cost of quinine treatment, 300 grains being taken as an average dose, is 12 annas. Taking quinine as unity, the relative costs of treatment are as follows :—

Treatment.	Cost.
Quinine salts	1·0
Atebrin-plasmoquine	1·92
Tebetren ..	2·25

SUMMARY.

Tebetren was tried in a series of 21 cases of malaria and the relapse rate was 14·3 per cent. Tebetren reduced the duration of the febrile period in malignant tertian malaria in comparison with quinine but had no advantage in benign tertian cases.

Fifteen cases treated with tebetren showed no toxic symptoms: of the remaining 6 cases, insomnia was fairly marked in 4 cases and delirium was noted in 3 cases. No bad after-effects followed treatment with tebetren.

The action of tebetren is not cumulative.

CONCLUSION.

Tebetren is an advance on quinine in the chemotherapy of malaria and is worthy of further trial. The 'relapse-reinfection rate' is considerably reduced and toxic after-effects are absent.

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Records of the Malaria Survey of India, 6, 1, March, 1936.

A DESCRIPTION OF THE LARVA OF *ANOPHELES GIGAS* VAR. *BAILEYI*.

BY

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[8th November, 1935.]

As no characteristics have been described previously whereby the larvæ of *A. gigas* var. *baileyi* can be differentiated from *A. gigas* var. *simlensis*, 209 larvæ of *A. gigas* var. (?) collected from streams and pools in Shillong were examined. Subsequently 60 specimens selected from these larvæ were successfully bred out to adults and were identified as *A. gigas* var. *baileyi*. Of the 60, that subsequently proved to be *A. gigas* var. *baileyi*, the following larval characteristics by which this variety may be differentiated from *A. gigas* var. *simlensis*, as described by Puri (1931), were noted (*vide* Table I).

DESCRIPTION OF THE FULL-GROWN LARVA OF *A. GIGAS* VAR. *BAILEYI*.

The full-grown larva of the 4th instar measures from 8 to 9 mm. in length. The colour of the larva varies from yellow to dark brown. Some larvæ have a white dotted marking on the dorsum of the thorax and of the third abdominal segment; that on the thorax is shaped somewhat like an inverted 'V'—with its apex towards the head. These markings appear to depend on the nature of the breeding place from which the larvæ are collected. They are noticeable only in the living state, and disappear when mounted in canada balsam.

THE HEAD.

Golden brown in colour with 7 to 10 dark brown, well defined markings on the suture behind the frontal hairs and adjoining the inner sutural hair.

TABLE I.

Comparative chart for varieties of A. gigas.

	A. gigas (type form).	*A. gigas* var. *simlensis.*	*A. gigas* var. *baileyi.*
Inner anterior clypeal hairs.	Long, thick, simple.	Long, thick, simple	Long, thick, simple.
Outer anterior clypeal hairs.	(*i*) Less than half length of inner clypeal hairs. (*ii*) Has 2 to 6 branches.	Almost always simple	Almost always simple but may have up to 3 branches or even be frayed.
Posterior clypeal hairs	Almost always simple, rarely one or both may be bifid.	Usually split into 2 to 5 branches, but may also be simple.	Variable, may be simple or have up to maximum 4 branches.
Hair No. 2 on second abdominal segment.	6 to 10 branches	4 to 6 branches	5 to 12 branches.
Lateral hair on IV abdominal segment.	3 to 5 branches	3 to 5 branches	2 to 3 branches.
Lateral hair on V abdominal segment.	2 to 3 branches	2 to 3 branches	Simple.

The inner clypeal hairs.—These are closely approximated, slender and very long (0·34 mm.), about the same length as the width of the anterior margin of the fronto-clypeus. They are usually simple, but may be bifid or even frayed (5 frayed in 209 larvæ examined).

The outer clypeal hairs.—These are slightly longer than one-third the length of the inner clypeal hairs (0·13 mm.). They are usually simple, but may be bifid or even frayed.

Posterior clypeal hairs.—These hairs are about half, or slightly more than half, the length of the outer clypeal hairs (0 08 mm.). They may be simple or branched; the maximum number of branches being 4. The branches may not be of the same number on both sides, and the branching may arise from the root or from the middle of the main hair.

The frontal hairs.—These are long, stout and feathery; the tips of the innermost pair reach the root of the anterior clypeal hairs. The branches are not, however, thickly set.

The inner sutural hairs.—These are about the same length as the outer anterior clypeal hairs (0·15 mm.) and usually have 6 to 9 branches.

The outer sutural hairs.—These are slightly stouter than the inner hairs, but the length and number of the branches are usually the same as those of the inner sutural hairs.

The antennae are about the same length as the inner anterior clypeal hairs (0·31 mm). The small spinous processes on the surface are thick and stout

towards the base of the antennæ, but slender on the distal portion. There are four appendages at the distal end of the antenna. *The antennal hair* is branched (4 to 8 branches), and rises from the dorso-internal surface, at about a quarter the length of the antenna from the base.

The mentum has 9 coarse teeth; the medium one is rounded with a row of four on each side; the most anterior tooth of the submentum is bifid.

THE THORAX.

The thorax of some living larvæ shows, as already mentioned, a peculiar V-shaped spotting on the dorsum.

The submedian prothoracic hairs.—The inner hair has no tubercle at its root. It is more slender than the middle hair and has 5 to 8 branches. The middle hair arises from a tubercle, is stout, has 8 to 11 lateral branches, and is twice the length of the inner hair. The outer hair is simple, arises near the middle hair and is the shortest of the group.

Hair No. 1 *on the metathorax* is not transformed into a palmate hair, but is short and has 10 to 12 branches.

Pleural hairs.—In none of the pleural hairs is the tubercle thick. The anterior pair of the *prothoracic* group are slender, long and simple. The inner hair of the dorsal pair is as long and as stout as the ventral pair. The outer hair is short and branched.

On the *mesothorax* all four hairs are simple:—The anterior pair are long. The inner hair of the posterior pair is slender and about one-third the length of the anterior pair. The outer hair is very short.

The anterior pair of the *metathoracic* group are long and simple. The inner hair of the dorsal group splits into 2 to 3 branches. The outer hair is short and simple.

THE ABDOMEN.

Hair No. 1 on segments I and II is not transformed into a palmate hair but is short and has 4 to 12 branches. There are more branches on the hair of the second segment than on that of the first. From segments III to VII this hair is transformed into a well developed *palmate hair.* The filaments of the palmate hairs are not long and drawn out, but are rather poorly differentiated. Hair No. 2 on the 2nd abdominal segment has 5 to 12 branches.

The lateral hairs on segments I to III are very long, stout and feathery. On segment IV, they are very long with 2 to 3 branches; on segment V the hair is simple and not as long as those of segments 1 to 4. On segments VI and VII the hairs are very short with 7 to 10 branches.

The pecten bears coarse spines, of which 13 are small and 8 long. The *saddle hair* is long and simple.

The caudal hairs.—The outer sub-median caudal hairs are long and slightly curved distally, the hooks being wide and poorly developed. The lateral hair of the anal segment is long and simple.

HABITAT.

In Shillong the larvæ have been collected from pools in running streams, in stagnant ponds with or without vegetation and weeds, from seepage and from marshy areas. Its preference seems to be for water with vegetable decomposition and in shade.

CONCLUSION.

The characteristic feature for differentiation of the two varieties is the simple lateral hair on the fifth abdominal segment in the case of *A. gigas* var. *baileyi*, as compared with branched ones in *A. gigas* (type) and its variety *simlensis*.

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Records of the Malaria Survey of India, **6**, *1*, *March*, *1936*.

STUDY OF THE BIONOMICS OF *ANOPHELES SUNDAICUS* (*A. LUDLOWI*) IN THE SALT LAKES OF CALCUTTA.

BY

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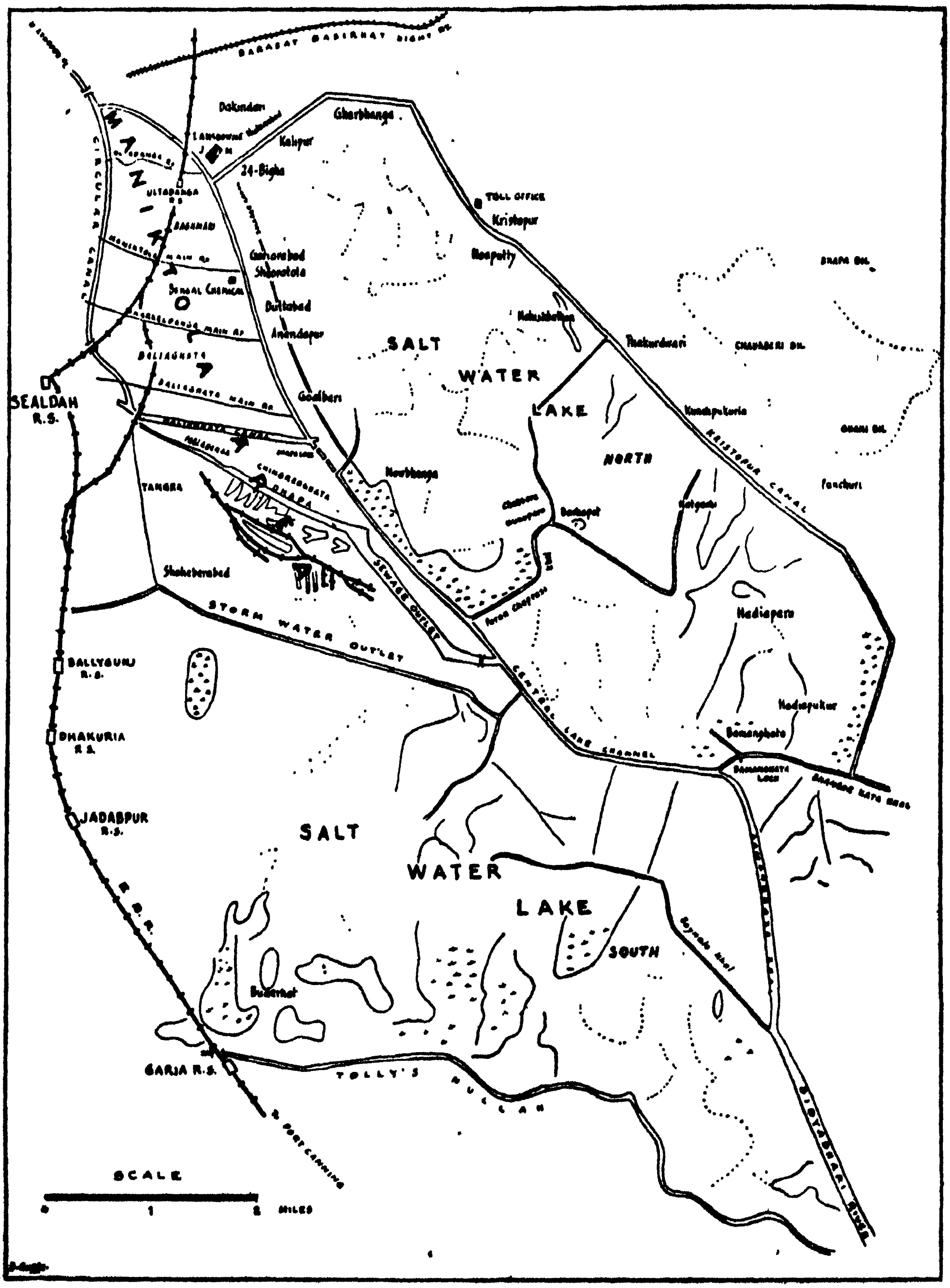
[2nd December, 1935.]

CONTINUED investigation of the spread of *A. sundaicus* since 1930 reveals that the problem of the establishment of this species in the Salt Lakes area, and the consequent menace of invasion to Calcutta, has gradually assumed much importance during recent years. Following upon the report of Mr. Iyengar on the outbreak of the malaria epidemic in the mill area of Budge Budge, the Director of Public Health to the Government of Bengal pointed out, in December 1930, the danger that would arise to the city of Calcutta if this species established itself in the Salt Lakes. The latter are swamps bordering the city to the east, and contain saline water varying in depth from a few inches to one and a half feet in the dry season, but increasing to three feet in the rains. They are covered with algæ and other floating vegetation, and the sullage of Manicktola and other adjacent areas is pumped into these swamps. Their present area is 13 1 square miles, of which 7 square miles are used as fisheries, 5 square miles form the lakes proper, and 1·1 square miles form paddy land*. The physical configuration of this area appeared very suitable for the growth and dissemination of *A. sundaicus*, but surveys made, both by Mr. Iyengar and by Dr. Ghosh, Entomologists of the Bengal Public Health Department, did not show the presence of *A. sundaicus* prior to December 1932, when this species was detected by Dr. Ghosh. Since then this dangerous species has become very important in and around Calcutta, because of the gradual spread of its zone of invasion over a wider and wider area, during the last two and a half years. In this connection it may be remembered that the earliest records of this species in Calcutta were made by Paiva (1912) and by Brahmachari (1912).

* Land used for rice cultivation.

MAP.


BARASAT BASIRHAT LIGHT RY.
SEALDAH R.S.
SALT WATER LAKE
NORTH
SALT WATER LAKE
SOUTH
TOLL OFFICE
Kristopur
Gharbhanga
24-Bighas
TANGRA
DHAPA
SEWAGE OUTLET
STORM WATER OUTLET
CENTRAL LAKE CHANNEL
KRISTOPUR CANAL
BALLYGUNJ R.S.
DHAKURIA R.S.
JADABPUR R.S.
E.B.R.
GARJA R.S.
TOLLY'S NULLAH
BIDYADHARI RIVER
Nadiapara
Nadiapukur
SCALE
0 1 2 MILES

The present investigation was undertaken to examine, one by one, some of the possible factors which might have influenced the breeding of *A. sundaicus* in the Salt Lakes within recent years. The factor of mechanical transportation in country boats of adult specimens of *A. sundaicus* from the Sunderbans, a locality where this species occurs normally, has been present ever since the cutting of the Kristopur and other navigation canals. It is, therefore, necessary to study the changes which have made it possible for this species to obtain a foothold in the Salt Lakes area in recent years. The following factors require investigation :—

(*i*) The salinity of the Salt Lakes area.

(*ii*) The presence of algæ.

(*iii*) The presence of organic pollution.

(*iv*) Atmospheric temperature, which may be a factor influencing the variation in the breeding of *A. sundaicus* but over which there is no control.

All the earlier workers have pointed out that this species of anopheline is a brackish water breeder, stands a certain amount of organic pollution in its breeding places, and is intimately associated with floating algæ.

Christophers (1933) mentions that 'apart from its special predilection for human blood, the outstanding features of its bionomics are its close association with coastal conditions and its preference for breeding in brackish water. The species breeds pre-eminently in salt swamps, collections of brackish water behind coastal bunds, and such-like situations (Lalor, 1912; Christophers, 1912; Covell, 1927, Andamans; Iyengar, 1931). In the Dutch East Indies it is especially associated with the numerous fish-ponds on the coast. It is usually found associated with vegetable and algal growth, especially the alga *Enteromorpha,* which forms a felt-work on the surface of water in the Javanese fish-ponds (*vide* Breeman, 1919, 1920; Walch and Schuurman, 1929). It was found breeding by Covell in clear water pools without vegetation on the coral beach. It is recorded as frequently breeding in polluted water (Lalor, 1912; Rodenwaldt and Essed, 1925)'.

Covell (1932), in his report on 'Malaria in Calcutta', has reviewed our knowledge of the bionomics of *A. sundaicus.* He states it 'is a brackish water breeder, but the percentage of salt found in its breeding places varies considerably in different instances. It has been found breeding profusely in water containing from 0·03 to 1·8 per cent of sodium chloride, and larvæ have also been found in concentrations approaching 3 per cent. Opinions vary as to the optimum amount of salinity for breeding. Thus, Rodenwaldt and Essed (1925) in the Dutch East Indies considered that from 1·2 to 1·8 per cent was the most favourable concentration, whilst Iyengar (1931*d*) at Budge-Budge found the optimum amount to be 0·15 to 0·25 per cent. Van Breemàn (1919) records *A. ludlowi* (*A. sundaicus*) as breeding freely in concentration of 0·03 to 2 per cent; Schüffner and Hylkema (1922) in from 0·04 to 1·25 per cent; Christophers (1912) in a single observation in 0·4 per cent'. Covell (1932) goes on to say that *A. sundaicus* 'favours those breeding places in which floating algæ (*Enteromorpha, Cladophora Cyanophyceae*) are present. The observations of the officers of the Bengal Public Health Department have shown that *A. ludlowi*

(*sundaicus*) is most frequently found in association with *Oscillatoria germinata, Lyngbya confervoides*, and *Oedogonium* sp. It will also breed, however, in water in which no algæ are present, or at any rate none visible to the naked eye'...... 'Schüffner and his co-workers also observed that in the coastal zone the larvæ were found in small pools, whether covered with grass, rushes or other plants or free from coarse vegetation'.

'*A. ludlowi*, unlike the majority of malaria carrying species of mosquitoes, can tolerate a considerable degree of organic pollution in its breeding places. Indeed, according to Rodenwaldt and Essed (1925) it actually favours breeding places which are heavily polluted. These observers state "Its cardinal condition is the presence of decaying matter. Thus, it is not hampered by the breeding places being strongly polluted with urine and with fæces"'. Iyengar (1931) mentions that the combination of the salinity factor, with the presence of a small amount of organic pollution, seems to be the optimum condition for the breeding of this species in the Budge-Budge area.

INVESTIGATION OF FACTORS WHICH MAY HAVE INFLUENCED THE BREEDING OF *A. SUNDAICUS* IN THE SALT LAKES AREA.

As *A. sundaicus* has, in recent years, established breeding places in the Salt Lakes area, which was previously free, it is necessary to consider in how far changes have occurred in the relative association of the different factors which have been reported to be favourable to the breeding of this species. The correlation between the breeding of *A. sundaicus* and the factors mentioned above, namely salinity, algæ, organic pollution, and temperature has been worked out. The present enquiry has been limited to conditions of the Salt Lakes proper. The tract of Bengal in which *A. sundaicus* can be found in nature is vast, and the number of actual '*sundaicus*' breeding places is infinitesimal in comparison with the number of water collections found in nature. The Salt Lakes area, being limited by some khals, namely Kristopur canal, New-cut canal, Central Lake channel, etc., and being saline, has been specially chosen for this investigation. The records on which the amount of association has been calculated were either left by my predecessors, or observed during my own investigations.

THE AMOUNT OF BREEDING IN THE SALT LAKES.

The field workers made collections of larvæ from the various fish-ponds, swamps, and bunded areas, all situated within the defined area of the Salt Lakes. The amount of breeding has been estimated by recording the percentage of water collections which showed the presence of *A. sundaicus* larvæ. Following the provision of special staff, intensive control measures were adopted in July 1933, and continued till February 1935. As, during this period, there was actually an attempt at the artificial reduction of *sundaicus* breeding, all figures, recorded during the period from July 1933 to February 1935, have been omitted in calculating the coefficient of correlation. The control measures which were undertaken in the Salt Lakes prior to July 1933 were merely nominal as there was no special arrangement for the purpose. The frequency distribution of the number of breeding places examined, and the number of samples infested with *A. sundaicus* in the Salt Lakes proper are shown in Table I.

TABLE I.

	1933.			1934.			1935.		
	Number examined.	Number positive.	Percentage	Number examined.	Number positive.	Percentage.	Number examined.	Number positive.	Percentage.
January ..	250	39	15·6	693	73	10·5	278	52	18·7
February ..	147	13	8·8	812	82	10·1	271	22	8·1
March ..	536	45	8·4	546	41	7·5	558	82	14·7
April ..	360	55	15·3	502	39	7·8	546	105	19·2
May ..	219	45	20·5	610	18	3·0	426	49	11·5
June ..	167	17	10·2	439	4	0·9	289	21	7·3
July .	440	33	7·5	563	13	2·3	438	2	0·5
August ..	421	70	16·6	375	3	0·8	418	25	6·0
September ..	273	44	16·1	243	5	2·1	.	.	..
October .	433	55	12·7	128	24	18·8	..	..	..
November ..	581	40	6·9	366	31	8·5	..	.	..
December ..	669	74	11·1	373	41	11·0	..	.	..

SALINITY OF WATER IN RELATION TO BREEDING OF *A. sundaicus*.

In the course of the investigation, the salinity of breeding places of *A. sundaicus,* as well as other water collections, was noted. Of the breeding places so far examined in which *A. sundaicus* larvæ could be found, the records of salinity of **863** samples have been discussed here, the abnormal ones having been left out. Table II shows the distribution of the number of samples falling under the different groups in the ranges of salinity. These breeding places are scattered all over the area, extending from Diamond Harbour to Calcutta, and between the rivers Hooghly and Ichhamutti. The lowest limit of salinity, in which *A. sundaicus* was found, was 7·8 parts per 100,000 parts, whereas the upper limit was 2,675 parts per 100,000 parts. Thus it is noticed that there is a wide range of variation.

TABLE II.

Frequency distribution in the different ranges of salinity.

Parts per 100,000 parts.	Frequency.	Parts per 100,000 parts.	Frequency.
0— 50	215	550— 600	5
50—100	207	600— 650	11
100—150	129	650— 700	1
150—200	79	700— 750	7
200—250	55	750— 800	8
250—300	35	800— 850	4
300—350	41	850— 900	3
350—400	19	900— 950	1
400—450	15	950—1,000	2
450—500	10	1,000—1,050	3
500—550	13	1,050—2,700	19

For the sake of calculation of the mean and median, the last group, that is 1,050 to 2,700, has been left out. The actual mean salinity of the first 21 groups, that is up to 1,050 parts per 100,000 parts, has been calculated to be 173·61 with the standard deviation of 187·29 ± 3·04. The median is placed at about 103·8, the lower quartile at 50·25 and the upper quartile at 215·45. Therefore, 50 per cent of the cases are found within the range of quartile deviation of salinity about the median, which is between 50·25 and 215·45 parts per 100,000 parts.

Chemical analysis of breeding waters of *A. sundaicus* in coastal districts at Selangor, F. M. S., showed an average chloride content of 398 parts with a standard deviation of 390, the whole range being from 4·8 to 1,370 parts per 100,000 parts (Kingsbury, 1935).

On further analysis of the group between 0 and 50, the frequency is found as follows :—

0—10	14	30—40	64
10—20	36	40—50	52
20—30	49		

The mode was found at the sub-group 30 to 40. The distribution curve (Chart I) is not that of a normal curve but shows a positive skewness. Quartile

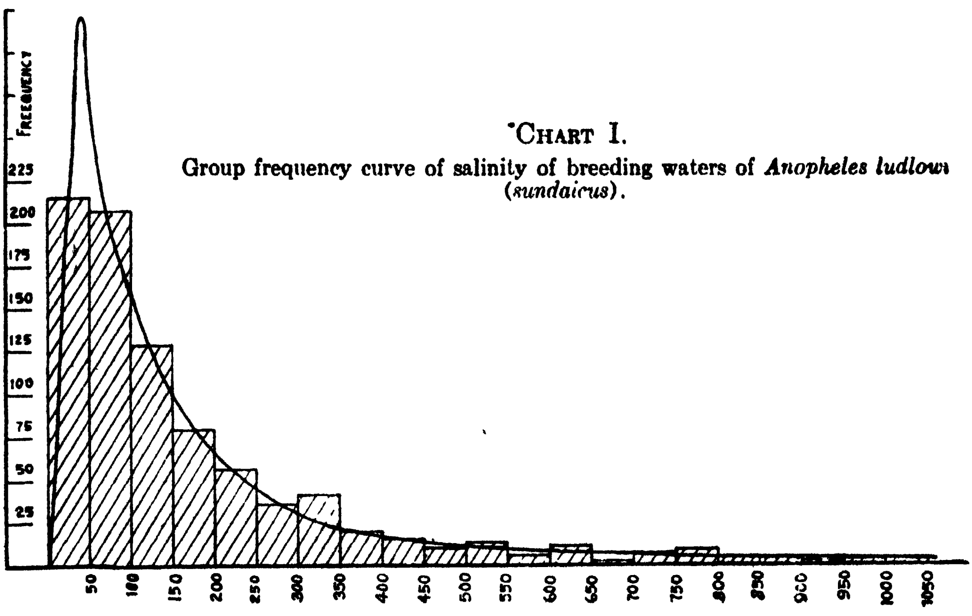


CHART I.
Group frequency curve of salinity of breeding waters of *Anopheles ludlowi* (*sundaicus*).

deviation being a fair measure of dispersion, the monthly variation on the percentage of samples examined for salinity in the Salt Lakes proper, and falling within the inter-quartile range of dispersion, has been shown in Table III.

TABLE III.

Frequency of samples within the range of salinity between 50·25 and 215·45.

	1933.			1934.			1935.		
	Number examined.	Frequency of salinity between 50·25 and 215·45.	Percentage.	Number examined.	Frequency of salinity between 50·25 and 215·45.	Percentage.	Number examined.	Frequency of salinity between 50·25 and 215·45.	Percentage.
January ..	..	..	..	24	12	50·0	44	41	93·2
February ..	..	..	..	62	28	45·2	10	9	90·0
March ..	31	8	25·8	50	34	68·0	31	17	54·8
April ..	36	20	55·6	53	25	47·2	50	29	58·0
May ..	54	37	68·5	..	..	..	26	14	53·8
June ..	24	10	41·7	..	..	..	12	7	58·3
July ..	27	19	70·4	..	..	..	30	14	46·7
August ..	21	9	42·8	4	0	0·0	25	15	60·0
September ..	17	2	11·8	..	..	..	..	..	..
October ..	13	6	46·2	17	8	47·1	..	..	..
November ..	61	39	63·9	23	11	47·8	..	..	..
December ..	26	20	76·9	37	24	64·9	..	..	..

PRESENCE OF AQUATIC VEGETATION ON THE SURFACE OF WATER IN RELATION TO BREEDING OF *A. sundaicus*.

With the samples of larvæ collected, the field workers generally sent samples of vegetation found in those water collections. These were identified and recorded. In some cases, however, no record was made either of the presence or absence of vegetation. For statistical purposes such cases have been left out. Only those cases, in which there is a definite record of either the presence or absence of any vegetation on the surface of the water, have been taken into consideration. In the case of *sundaicus* breeding places, the following kinds of vegetation were found on the surface:—macroscopic floating algæ were associated with *sundaicus* in 50·8 per cent cases, *Hydrilla* in 30 9 per cent, *Lemna* in 21 4 per cent, 'water hyacinth' in 2·6 per cent, and *Pistia* in 0 3 per cent.

As floating algæ were the chief form of vegetation associated with *A. sundaicus*, only this will be taken into consideration in studying the amount of association between it and the breeding of this anopheline in the Salt Lakes proper. For this purpose the monthly records of the 10 months, that is March to June 1933, and March to August 1935, in which period practically no control measures were adopted in the Salt Lakes, have been examined, and the result is stated in Table IV.

TABLE IV.

		Number of samples examined.	Number found with algæ.	Percentage.
1933	March ..	422	339	80·3
	April ..	200	179	89·5
	May ..	105	84	80·0
	June ..	118	64	54·2
1935	March ..	327	197	86·8
	April ..	371	209	56·3
	May ..	337	198	58·8
	June ..	251	118	47·0
	July ..	354	97	27·4
	August .	349	82	23·5

PRESENCE OF ORGANIC POLLUTION IN RELATION TO BREEDING OF *A. sundaicus*.

It has been stated by previous workers that *A. sundaicus* can stand a certain amount of organic pollution. As an indication of the organic pollution the amount of albuminoid ammonia present in the water of the breeding places of this mosquito, as well as in other collections in the neighbourhood, was estimated.

The frequency distribution of *sundaicus* breeding in the different groups of ranges of albuminoid ammonia is as shown in Table V. Here also, as in the case of salinity of the *sundaicus* breeding places, the curve shows a positive skewness (Chart II). The median is placed at 0·083 part per 100,000 parts, the

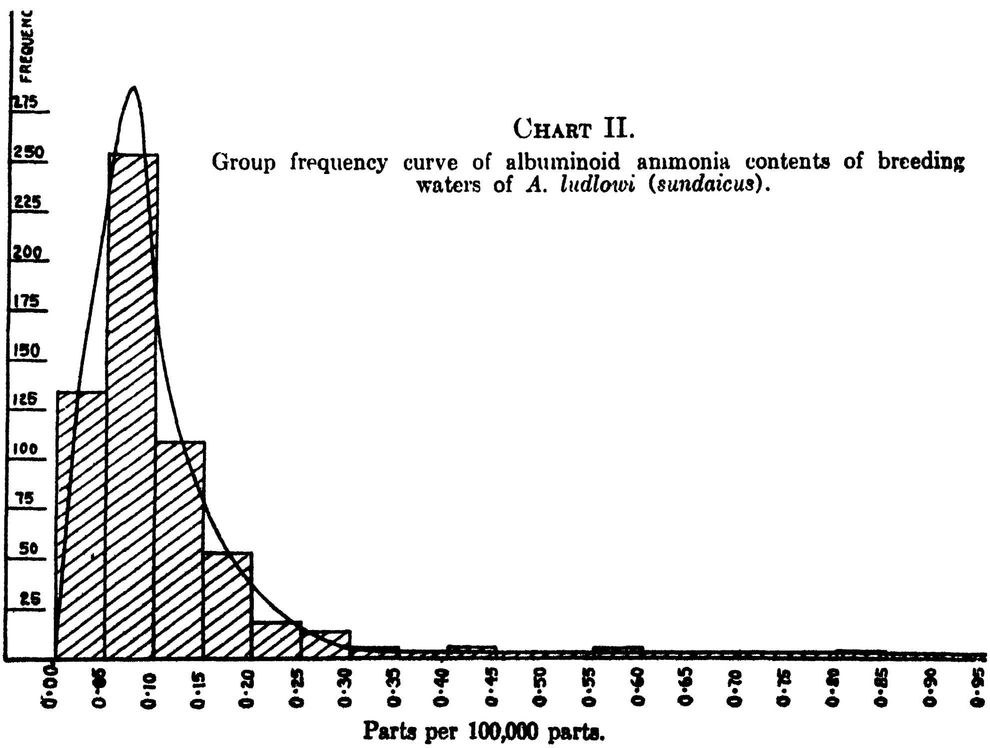


CHART II.
Group frequency curve of albuminoid ammonia contents of breeding waters of *A. ludlowi* (*sundaicus*).

lower quartile at 0·054 and the upper quartile at 0·14. The inter-quartile range of dispersion about the median in this case is therefore 0.054 to 0·14 part per 100,000 parts.

TABLE V.

Group.	Frequency.	Group.	Frequency.
0·00–0·05	133	0·50–0·55	0
0·05–0·10	254	0·55–0·60	4
0·10–0·15	108	0·60–0·65	1
0·15–0·20	52	0·65–0·70	2
0·20–0·25	17	0·70–0·75	1
0·25–0·30	13	0·75–0·80	0
0·30–0·35	6	0·80–0·85	2
0·35–0·40	2	0·85–0·90	0
0·40–0·45	5	0·90–0·95	0
0·45–0·50	2	0·95 and up	4

The lowest limit was at 0·002 and the upper limit at 1 2 parts per 100,000 parts.

To ascertain the degree of its association with the amount of *sundaicus* breeding in the Salt Lakes proper, the monthly rate of the frequency of samples, which came within the range of inter-quartile dispersion of albuminoid ammonia in the Salt Lakes, and examined in the above-mentioned 10 periods was studied (Table VI).

TABLE VI.

		Total samples examined for albuminoid ammonia.	Number within the range of 0·05 to 0·14.	Percentage.
1933	March ..	31	10	32·3
	April ..	31	14	45·2
	May ..	54	33	61·1
	June ..	20	14	70·0
1935	March .	30	22	73·3
	April ..	50	34	68·0
	May ..	26	15	57·7
	June ..	12	9	75·0
	July ..	30	17	57·7
	August ..	25	19	76·0

TEMPERATURE IN RELATION TO BREEDING OF *A. sundaicus*.

The next factor, over which one has no control but which may have an influence over the growth of larvæ, is the maximum temperature. To find out the coefficient of correlation between the mean monthly maximum temperature and the amount of breeding of *sundaicus* in Salt Lakes, the mean of the daily maximum temperature of the 10 months, as recorded at Bowbazar Observatory,

Calcutta, has been determined, and is given in Table VII. The daily figures on which the monthly averages are based, were kindly supplied by the Protozoological Department of the Calcutta School of Tropical Medicine.

TABLE VII.

		Mean monthly maximum temperature. °F.	Mean monthly minimum temperature. °F.
1933	March ..	97·3	73·3
	April ..	97·9	76·0
	May ..	96·0	77·6
	June ..	96·5	78·9
1935	March ..	96·1	72·9
	April ..	98·7	76·8
	May ..	101·2	81·5
	June ..	96·7	80·6
	July ..	91·5	79·3
	August ..	91·1	78·6

DISCUSSION ON THE VARIOUS FACTORS INFLUENCING THE BREEDING OF *A. sundaicus*.

In the above paragraphs the five variables, namely, the amount of breeding, salinity, food and shelter (algæ), the organic pollution, and the maximum temperature, have been described. For the purpose of determining the coefficient of correlation between these factors, Table VIII has been prepared.

TABLE VIII.

Salt Lakes zone.

		Percentage of *ludlowi* breeding places.	Percentage of samples falling within the quartile dispersion range of salinity.	Percentage of samples showing algæ.	Percentage of samples falling within the quartile dispersion range of albuminoid ammonia.	Mean maximum temperature. °F.
		1	2	3	4	5
1933	March ..	8·4	25·8	80·3	32·3	97·3
	April ..	15·3	55·6	89·5	45·2	97·9
	May ..	20·5	68·5	80·0	61·1	96·0
	June ..	10·2	41·7	54·2	70·0	96·5
1935	March ..	14·7	54·8	86·8	73·3	96·1
	April ..	19·2	58·0	56·3	68·0	98·7
	May ..	11·5	53·8	58·8	57·7	101·2
	June ..	7·3	58·3	47·0	75·0	96·7
	July ..	0·5	46·7	27·4	57·7	91·5
	August ..	6·0	60·0	23·5	76·0	91·1

It has been explained previously that the period from July 1933 to February 1935 has been excluded because intensive anti-*ludlowi* control measures were adopted during this period, thus causing an artificial reduction in the amount of breeding.

The standard deviations of the above five items have been calculated to be as follows :—

$\sigma_1 = 5{\cdot}8765 \pm 0{\cdot}8863$	$\sigma_4 = 13{\cdot}3574 \pm 2{\cdot}0146$
$\sigma_2 = 11{\cdot}2053 \pm 1{\cdot}6900$	$\sigma_5 = 2{\cdot}8937 \pm 0{\cdot}4364$
$\sigma_3 = 22{\cdot}3867 \pm 3{\cdot}3764$	

and the coefficients of correlation between each and one of the others have been calculated to be as follows :—

$R_{12} = 0{\cdot}4559 \pm 0{\cdot}1689$	$R_{13} = 0{\cdot}6906 \pm 0{\cdot}1116$
$R_{14} = 0{\cdot}0075 \pm 0{\cdot}2133$	$R_{15} = 0{\cdot}5738 \pm 0{\cdot}1431$
$R_{23} = -0{\cdot}0764 \pm 0{\cdot}2121$	$R_{24} = 0{\cdot}6079 \pm 0{\cdot}1345$
$R_{25} = -0{\cdot}0538 \pm 0{\cdot}2127$	$R_{34} = -0{\cdot}4734 \pm 0{\cdot}1655$
$R_{35} = 0{\cdot}5890 \pm 0{\cdot}1393$	$R_{45} = -0{\cdot}2861 \pm 0{\cdot}1958$

Interpretation of findings.

The correlation between the breeding of *A. sundaicus* and salinity has been found to be positive and high. Similarly the coefficient of correlation between the breeding of this insect and its food supplies, namely algæ, is also positive, high and significant. There is no correlation between the breeding of *A. sundaicus* and the presence of albuminoid ammonia. The latter may simply mean that the larvæ of this mosquito can stand a certain amount of organic pollution, but their growth is not influenced by it in the amounts found. The correlation between the amount of breeding and the mean maximum temperature is high and significant. There is practically no correlation between the salinity and the presence of algæ, whereas there is high correlation between the salinity and the organic pollution. The latter may mean that the variation of chloride contents may be due to animal organic pollution. There is no correlation between the salinity and temperature. The growth of algæ is negatively correlated with the organic pollution, while positively correlated with temperature. The correlation between the organic pollution and the temperature is negligible and not significant.

It will be observed from these considerations that the five factors which have been found to influence the breeding of *A. sundaicus* do not all act in the same direction. Thus while one factor may be optimum another may be very unfavourable. An attempt has been made to study the influence of some of these factors individually when other factors remain constant. In other words, what is the coefficient of correlation between the presence or development of larvæ and salinity, when other factors such as algal growth, organic pollution and temperature remain constant ? Similarly what is the coefficient of correlation between the presence or development of larvæ and organic pollution, when other factors remain constant, etc.?

The calculations have been made by Yule's method of partial correlation, the formula being

$$R_{12\,34\ldots n} = \frac{R_{12\cdot 34 \ldots (n-1)} - R_{1n.34\ldots(n-1)} \times R_{2n.34\ldots(n-1)}}{\left\{1 - R^2_{1n.34\ldots(n-1)}\right\}^{\frac{1}{2}} \left\{1 - R^2_{2n.34\ldots(n-1)}\right\}^{\frac{1}{2}}}$$

In calculating $\sqrt{(1-r^2)}$, Miner's tables have been largely used*. Thus we find,

(1) the coefficient of correlation between breeding and salinity, keeping the other factors 3, 4, and 5 constant, to be as follows :—

$R_{12\,345} = +0\ 6012 \pm 0\ 1362$, which is positive, high and significant;

(2) the coefficient of correlation between breeding and the presence of algæ keeping the other factors 2, 4 and 5 constant, is :—

$R_{13\,245} = +0\ 6910 \pm 0\ 1114$, which is also high, positive and highly significant;

(3) the coefficient of correlation between breeding and organic pollution, keeping the other factors 2, 3, and 5 constant, is :—

$R_{14\cdot 235} = +0\cdot 1373 \pm 0\ 2093$, which is low, positive and of no significance.

Salinity.—In the course of the present discussion of the Salt Lakes it has been found by partial correlation that the coefficient of correlation between the number of breeding places of *A. sundaicus* and the salinity of water collections in this area is high, and significant (0 6012 ± 0·1362). This means that the present state of salinity in this lake is suitable for the development of *A. sundaicus*. It was noted before that previous surveys in the Salt Lakes by Mr. Iyengar and Dr. Ghosh did not reveal the presence of this species of anopheline until December 1932. But from this time onward a sequence of events has developed, steadily and progressively, which is in striking contrast to the past. In explanation of the past failure, and the recent success in finding *sundaicus* larvæ, it may be argued that the degree of salinity was formerly in all probability high and unfavourable, and has gradually come down within recent years to a range suitable for the breeding of *A. sundaicus*. There is no direct evidence in support of this argument in the older water-analysis records to show that the degree of salinity was formerly high. The following results, however, suggest that the degree of salinity is steadily coming down.

(*a*) The results of water analysis done by Mr. K. P. Biswas (1926. 1928), and in the laboratory of the Public Health Department, Bengal (1935), are shown in Table IX.

(*b*) That the water of the Lakes contained a large percentage of salt was indicated by the fact that a few years ago there was profuse white incrustation of salt on a large part of the Salt Lakes region during the hot months, and also isolated patches of thick deposit of salt on the bunds (embankments) and dry part of the lakes in other seasons (K. P. Biswas). This profuse incrustation is no longer found.

* For details of these calculations the reader is referred to two tables available from the Library of the Malaria Survey of India, Kasauli. These have been omitted from the paper due to scarcity of space.—*Editor.*

TABLE IX.

	Name of place.	Date.	Total chloride content parts per 100,000 parts.
1	† Canal off Lansdown Jute Mill ..	13th May, 1926	1,822 (low tide).
2	† Ditto ..	14th May, 1926	1,848 (high „).
3	† Ditto ..	23rd February, 1928	960
4	* Ditto ..	19th August, 1935	16
5	† North of the Lakes	13th May, 1926	1,537 (low tide). 1,718 (high „).
6	† Ditto ..	24th February, 1928	2,366
7	† Bidyadhari river north end .	28th April, 1928	1,373 (low tide).
8	† Ditto near Chingrighata lock gate	8th July, 1928	285 (high „).
9	* Bidyadhari river near Bemanghata lock.	23rd August, 1935	5
10	† Paranchaprasi khal . ..	28th April, 1928 8th July, 1928	1,548 (low tide). 597 (high „).
11	* Ditto	20th August, 1935	27
12	† Salt Lakes proper	28th April, 1928	1,499 (low tide).
13	* Ditto	23rd August, 1935	94
14	† New-cut canal at Chingrighata lock gate.	9th July, 1928	467 (low tide).
15	* Ditto ..	16th August, 1935	144
16	* Chingrighata khal	16th August, 1935	23

* Examined by Bengal Public Health Department.
† Examined by Mr. K. P. Biswas.

(*c*) The fish-ponds and tanks within the Salt Lakes zone, that were formerly used to rear salt-water fish, now allow fresh-water fish to be cultured. In the local bazars, fish of the fresh-water carp type have now replaced, to a large extent, the saline-water 'Bhektis', which used to be found in abundance 3 or 4 years ago. The local fishermen say that this change is due to the shutting out of tidal water from the river Bidyadhari.

(*d*) Introduction of rice cultivation in parts of the Salt Lakes zone is another proof that the soil is getting less saline, and that the water on the rice fields is fairly sweet, otherwise the land could not have been used for such a purpose.

This change in the salinity in the Salt Lakes has been brought about by the cessation of the tidal influence of the Bidyadhari river. In Capt. Claud Martin's map (1760–64), it is mentioned that 'the water supply of these lakes was then entirely tidal derived directly from the sea by a deep winding creek which flows from the most southernly point of the lake and joins itself with another sunderban canal'.

The Bidyadhari river is fed by tides of two important rivers, namely, the Piali and the Matla. During recent years, however, the river Bidyadhari, the Central Lake channel and other associated water channels, have undergone rapid silting up. This has caused a direct change in the physical configuration of the Salt Lakes. The other causes which further enhanced this change are (*i*) the method of fish culture by bunds (embankments), (*ii*) reclamation of parts of the Salt Lakes for paddy cultivation, and (*iii*) the sewage outfall of

Calcutta which has given a death blow to the Central Lake channel and to the river within recent years. So there is no longer any tidal flow in these water channels, and the Salt Lakes area no longer forms the spill basin of the Bidyadhari. As the result of the silting up of the river, and thus the cessation of tidal influence, there is no longer any influx of saline water to maintain a constant degree of salinity, nor to supply the loss of salt which occurs continually from year to year through the effect of rainfall. Thus the range of salinity is actually falling lower and lower since the cessation of the tidal influence of the river. The rapidity of this loss will depend upon the amount of annual rainfall. In years of heavy rainfall, causing inundations and overflow, this loss will be considerable.

Thus the present establishment of *A. sundaicus* in an intensive manner in the Salt Lakes area may reasonably be ascribed to this change in the range of salinity, which is now favourable for this species.

Aquatic vegetation.—Now the range of salinity having come down to a suitable limit, the presence of algæ, by supplying food to the growing larvæ and shelter against their natural enemies, further helps this species to gain a permanent footing in the Salt Lakes. The association of algæ with the amount of breeding of this species has been noted to be very intimate, the coefficient of correlation being $0{\cdot}6910 \pm 0\ 1114$. The loss of tidal influence, having brought about a condition of stagnancy, favours the growth of floating algæ.

Organic pollution.—Previous workers stated that *A. sundaicus* can tolerate a certain amount of organic pollution in its breeding places. Iyengar (1931) observed that the combination of a small amount of organic pollution with the proper salinity appears to form an optimum condition for the breeding of this species. By partial correlation, the amount of association of organic pollution with the intensity of breeding has been calculated to be $0{\cdot}1373 \pm 0{\cdot}2093$, which does not signify any correlation. The presence of gross organic pollution in the Salt Lakes is due to the sullage water pumped out of the Manicktolla areas through 4 pumping stations, and to decaying vegetable matter.

REMEDIAL MEASURES.

A. INCREASE OR DECREASE IN THE SALINE CONTENT OF WATER IN BREEDING PLACES.

If the increased prevalence of *A. sundaicus* which has been observed in recent years in the Salt Lakes of Calcutta is attributable to alterations in the salinity of the water in these lakes, it seems probable that good results might be achieved by increasing or decreasing the saline content of the water to a degree which would be unfavourable for the growth of the larvæ of *A. sundaicus*. This might be brought about by either natural or artificial means.

(*i*) ***Reduction of the saline content.***—The physiographical changes which have been taking place in this region during recent years have been shown to be responsible for a reduction in the saline content of the lake water. A further reduction in salinity would probably render this water unsuitable for the larvæ of *A. sundaicus*, provided the saline content were reduced to a sufficiently low degree. The fulfilment of this condition may be brought about in the course of time by natural conditions, but would be an uncertain and lengthy process.

Artificial means might be employed to achieve similar results. It is suggested that the area might be flushed by sweet silty water from the Hooghly river with the following objects in view :—

(*a*) reduction in the saline content of the water to such a degree as to render it unsuitable for breeding of *A. sundaicus*.

(*b*) obliteration of existing depressions and excavations in the lake bed by the deposition of silt.

(*c*) eventual reclamation of land due to silting, which might be utilised for building or cultivation.

(*ii*) *Increase in the saline content.*—If the saline content of this lake water were to be raised sufficiently high, it would be expected that *A. sundaicus* breeding would automatically cease. The only way in which this end could be achieved would appear to be in re-establishing the tidal influence of the Bidyadhari river. This would necessitate dredging this river. Attempts to do this were made but had to be discontinued as the dredging operations were unable to keep pace with the deposition of silt (Sewell, 1934). In the expert opinion of the Irrigation Department of Bengal, the Bidyadhari is practically 'dead', and there seems to be little hope that this river can be utilised to revive the tidal condition of this area.

B. CONTROL OF ALGAL GROWTH AND VEGETATION IN THE BREEDING PLACES OF *A. SUNDAICUS*.

It has been found that the breeding of *A. sundaicus* can be inhibited by the removal of vegetation and algal growth, which afford food and shelter for the larvæ. In our experience such a procedure is effective so long as the water is free from vegetation, but as soon as it tends to grow again, *sundaicus* larvæ reappear. One of the following methods may be used for the removal or destruction of algal and other vegetation :—

(*i*) *Hand removal.*—This may either be done by a specially appointed staff, or by compelling the owners to do the work under some anti-malarial legislation. Very careful and continuous supervision will, however, always be necessary.

(*ii*) *Chemical algicides*, such as treatment of this area with some algicidal chemicals like copper sulphate. One of the chief disadvantages of this method is that persons interested in pisiculture may object to it, and that mortality amongst fish from whatever cause will be ascribed to its application.

(*iii*) *Pasoeran method.*—This method of keeping the fish ponds free from algæ was adopted in east and west Java. It makes provision for the ponds to be emptied periodically, the fish taking shelter in special ditches dug round the edges of the bottom of the pond. The floating algæ, which settle down to the bottom, are exposed to the sun and desiccated. After two days' exposure, water is readmitted during high tide and the level is adjusted. This method was applied in Java once a month originally but, later on, quarterly drying was considered to be sufficient. Such a method is not practicable in this area because the presence of tide is essential to obtain changes in the water level. This again would mean that revival of the Bidyadhari is necessary.

C. CONTROL BY LARVICIDAL FISH.

The control over the breeding places by cultivation of larvicidal fish in different collections of water in the Salt Lakes is not likely to be of much use, because in the presence of aquatic vegetation, especially matted algæ, larvicidal fish have a very limited value. There are a large number of fish ponds which harbour plenty of these larvicidal fish, but, in spite of their presence, larvæ are still found to grow in an unrestrained manner all the year round. To make these fish useful it is essential to keep the fish ponds scrupulously free from aquatic vegetation.

D. 'SPECIES SANITATION OF SWELLENGREBEL'.

This is the method of treatment which the '*anti-ludlowi*' staff of the Bengal Public Health Department have used for a long time. This requires a close and constant watch by a survey party, whose duty it is to find out what water collections get infested with *A. sundaicus*, and to point them out to the proper authority to take control measures. Its advantage over indiscriminate control is that there is a huge saving in labour and larvicide. Its drawbacks are that, besides the constant watch, the work requires to be carried on from year to year and it does not deal with the problem permanently.

SUMMARY.

(1) The Salt Lakes area is an extensive swamp containing saline water of varying depth from a few inches up to as much as three feet during rains.

(2) The close proximity of breeding places of *A. sundaicus* in this area is a menace to the health of Calcutta.

(3) *Anopheles sundaicus* was first recorded in Calcutta by Paiva (1912) and Brahmachari (1912), but there was practically no record of this species breeding in the Salt Lakes prior to December 1932.

(4) The range of salinity of the breeding places of *A. sundaicus* is from 7·8 parts to 2,675 parts per 100,000 parts, the mean being 173·61 with a standard deviation of 187·29 ± 3·04. The median is at 103·8, the lower quartile at 50·25 and the upper quartile at 215·45. The frequency curve shows a positive skewness.

(5) The larvæ of *A. sundaicus* are associated with floating algæ in 50·8, *Hydrilla* in 30·9, *Lemna* in 21·4, 'water hyacinth' in 2 6 and *Pistia* in 0·3 per cent of cases.

(6) Albuminoid ammonia as an indicator of organic pollution varies from 0·002 part to 1·2 parts per 100,000 parts in the *sundaicus* breeding places. The frequency curve shows a positive skewness. The median is at 0·083, the lower quartile at 0·054 and the upper quartile at 0·14 part per 100,000 parts.

(7) The coefficients of correlation between (*i*) the frequency of breeding places in the Salt Lakes and the different variables such as (*ii*) salinity, (*iii*) algæ, (*iv*) organic pollution and (*v*) the mean monthly maximum temperature have been determined by the method of partial correlation. The results are

$R_{12\cdot345} = 0\cdot60 \pm 0\cdot14$ = high, positive and significant.

$R_{13\cdot245} = 0\cdot69 \pm 0\cdot11$ = high, positive and highly significant.

$R_{14\cdot235} = 0\cdot14 \pm 0\cdot21$ = low, positive and not significant.

(8) In the past the Salt Lakes were under the tidal influence of the Bidyadhari river, so it is presumed that the water was highly saline.

(9) The cessation of this tidal influence within recent years has resulted in stagnation of water and lowered salinity, thus making the area very suitable for the breeding of *A. sundaicus.*

(10) Until the salinity of this area is brought outside the optimum range which is favourable for the development of *A. sundaicus*, the problem is likely to remain a permanent one.

(11) This change of salinity might be achieved either by introducing silt-laden sweet water during the rains from the river Hooghly, thereby making the water non-saline, or by introducing saline tidal water from the river Bidyadhari to make it more saline.

(12) Restoration of tide through the Bidyadhari is impracticable in the present state of that river.

(13) Introduction of silty water from the Hooghly river is more desirable, even if the use of pumps be necessary, as it will make the water non-saline. Such a procedure will also raise the ground level, making it suitable for either cultivation or habitation after the deposition of silt. The industries of Calcutta may then be advantageously located here.

(14) Until permanent measures as suggested above be adopted, the present method of dealing with the problem (species sanitation of Swellengrebel) must be continued.

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A RECORD OF AN INVESTIGATION TO DETERMINE THE ANDROPHILIC INDICES OF CERTAIN ANOPHELINE MOSQUITOES COLLECTED ON TEA ESTATES IN ASSAM AND NORTHERN BENGAL*.

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[28th December, 1935.]

ON studying the findings of the infectivity surveys that have been carried out in the province of Assam and in the tea districts of Northern Bengal, it appeared that an investigation into the feeding habits of the local anopheline mosquitoes might offer some explanation for the variation in the infectivity indices in the different species. A research was therefore organised with the help of Col. R. N. Chopra, C.I.E., I.M.S., Director, School of Tropical Medicine, Calcutta.

The material was collected from various tea estates in Assam and Northern Bengal and was sent to the Department of the Imperial Serologist, Government of India, for examination.

* A research carried out during the years 1933 and 1934.

Mosquitoes that had recently ingested a blood meal were collected from human habitations and cattle-sheds in the coolie lines. They were identified, the abdomen severed and the stomach contents of each expelled on to a filter paper (Whatman's No. 4). Precautions were taken to separate the blood-stained filter papers from each other to prevent possible contamination. In most cases, batches of specimens were sent weekly to Calcutta from each centre, the species of each specimen and place in which it had been captured being recorded.

The existing conditions with regard to the housing of the labour forces are closely similar in all districts—coolies living in houses with walls of bamboo and mud, or in some cases, of brick, with roofs of corrugated iron or of thatch. The cattle-sheds are usually adjacent to the coolie houses and separated only by a partial partition of bamboo or brick. Windows, if present, are generally mere openings in the walls; doors are usually of bamboo and there is free ingress and egress for mosquitoes to both cattle-sheds and human habitations. Mosquito-nets and other means of protection from bites, except for the repellent effects of the wood-smoke of cooking fires, are rarely used. In the area from which collections were made the human population totalled 122,205 and the population of ruminant animals was 95,990. In the cattle-sheds there is a less smoky atmosphere, a much larger skin surface is available for biting and there is greater opportunity for an uninterrupted feed. Mosquitoes could, both by day and night, be found very much more easily in cattle-sheds than in human habitations. Much more time, however, was spent collecting in houses than in cattle-sheds and actually approximately equal numbers were caught from each source. During the cold weather when the minimum night temperatures fell below 60°F., there was definite difficulty in collecting specimens with recently ingested blood, as compared with the warm steamy monsoon season. The time spent searching in cattle-sheds and human habitations was not recorded, but there was an actual numerical preponderance of all species, with the possible exceptions of *A. minimus* and *A. leucosphyrus,* in cattle-sheds. Frequently, specimens caught from cattle-sheds were found to contain human blood.

The specimens sent to the Department of the Imperial Serologist, School of Tropical Medicine, Calcutta, were tested with precipitin antisera specific against human and ruminant animal blood, each specimen being recorded as positive to one or other serum, to both, or to neither. In 3,720 specimens sent for examination, positive blood identifications were obtained in 3,347. Of the balance, namely, 373, the origins in most of them could not be traced, probably due to prolonged digestion of the blood in the stomachs of the mosquitoes, and in some the specimens were too small for further analysis of blood meals from other animals. Of the undetermined specimens it is interesting to note that the highest proportion was in the case of *A. vagus* and *A. subpictus*—these species may have a special predilection for blood other than human or ruminant. If we exclude species where less than a hundred specimens were tested, we find that a proportion of all species, except *A. splendidus,* have fed on human blood, indicating that, with the possible exception of the latter species, none of the species is exclusively zoophilic in nature. Further, with the exceptions of *A. splendidus* and *A. annularis,* one or more individuals in all the species were found to contain ruminant and human blood, suggesting that no individual in any of the species is exclusive in its choice of a blood meal.

TABLE.

	Total number examined.	Number with human blood only	Number with mixed blood, human and ruminant.	Number with ruminant animal blood only.	Number with source of blood undetermined.	Androphilic indices.
A. minimus ..	622	517	16	29	60	85·7
A. leucosphyrus	102	75	2	22	3	75·5
A. karwari .	311	50	1	255	5	16·4
A. philippinensis	343	18	4	290	31	6·4
A. maculatus ..	130	6	1	119	4	5·4
A. hyrcanus var. *nigerrimus.*	453	10	7	415	21	3·8
A. kochi ..	213	..	8	203	2	3·8
A. subpictus ..	326	4	2	255	65	1·8
A. annularis ..	192	3	..	175	14	1·6
A. vagus ..	593	4	1	470	118	0·8
A. splendidus ..	214	..	..	203	11	..
A. barbirostris ..	80	1	1	71	7	..
A. jamesi ..	72	1	1	52	18	..
A. culicifacies ..	31	9	..	10	12	..
A. jeyporiensis	17	9	1	6	1	..
A. aconitus ..	10	2	..	7	1	..
A. tessellatus ..	5	..	1	4	..	..
A. aitkeni ..	4	..	..	4	..	..
A. majidi ..	2	..	..	2	..	..

With regard to specimens with mixed blood, the method that seems to be most commonly adopted in an investigation into the feeding habits of insects, is to apportion half those representing mixed bloods to each source. This procedure has not been adopted by us, as the factor with which we are concerned is the importance of mosquitoes as malaria vectors. The fact that a feed of human blood has been incomplete does not halve the risk of ingestion of gametocytes or injection of sporozoites. In all cases where over a hundred specimens have been examined, we have calculated the androphilic index as the percentage that has, at any one meal, chosen human blood for part of, or for the entire feed.

The infectivity surveys that have been carried out by the Ross Institute Organisation in Assam and Northern Bengal have shown that in over 100,000 dissections 98·3 per cent of the specimens infected with malaria have been *A. minimus.* The precipitin tests demonstrate that this species is markedly androphilic.

Anopheles leucosphyrus would also appear to have a preference for human blood, but so far this species has not been found by us to be a vector. *A. leucosphyrus* is not prevalent in the area under investigation, but further researches are being carried out with a view to obtaining more data.

The zoophilic habits of *A. maculatus* and *A. philippinensis* in Assam and Northern Bengal will be of interest to workers in areas where these species are important as vectors.

Regarding *A. culicifacies,* it is unfortunate that we were unable to obtain more specimens, as this species has been found by us to be a vector. *A. culicifacies* is fairly prevalent during the early months of the year, but does not appear to find suitable breeding conditions during the monsoon season, and specimens with blood meals were difficult to find during the malaria transmission season.

We have found a gland infection in *A. annularis* and gut infections in *A. kochi,* but the infection rate of both these species is low, and both appear to be markedly zoophilic in nature.

Further, one gut infection, in over 2,000 dissections of *A. jeyporiensis,* was discovered, but insufficient specimens were collected for conclusions to be drawn as to its feeding habits.

Of the remaining species, *A. karwari* and *A. hyrcanus* var. *nigerrimus* were very prevalent throughout the area under investigation, but so far we have been unable to incriminate either as a vector of malaria, although over 15,000 specimens of each species have been dissected during our infectivity surveys.

CONCLUSIONS.

This research has shown that *A. minimus,* which is the principal vector of malaria in Assam and Northern Bengal, is markedly androphilic.

Some species, which are important vectors of malaria in other parts of the Oriental region, have been found in the area under investigation to be markedly zoophilic. This fact may account for these species being comparatively unimportant as vectors of malaria on tea estates in Assam and Northern Bengal.

Further investigations, however, on feeding habits appear to be necessary with several of the species where insufficient data have been obtained.

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MALARIAL PREVALENCE IN ITS RELATIONSHIP TO THE PROBLEMS OF FOOD SUPPLY AND INCREASING POPULATION IN INDIA.

BY

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'In man's history food may be claimed to have been of immensely greater importance than climate' (Osborne, 1920).

'Many of the richest agricultural lands in warm climates cannot be developed until the (malarial) infection in these regions has been brought under control' (Rose, 1919).

During the 60 years that have elapsed since the first Indian census was taken in 1872, the population of this country has increased by 46·6 per cent, while during the last census period (1921—31) alone, the recorded increase has been 10·6 per cent. As a result, the population in British India is now about 271½ millions and in Indian States about 81½ millions, making a total of about 353 million persons in the Indian Empire. This enormous growth has given rise to a problem of the greatest national importance, namely—how are these increasing millions to gain an adequate livelihood in the future?

In a recent paper, the problem of population growth in relation to the actual and potential food supplies of India, has been discussed in some detail by Russell and Raja (1935). These authors state that 'there seems to exist, in fact, a reasonable fear that this question may well be one of the most urgent problems facing the Federal and Provincial Governments which will shortly come into being under the new constitution'. They consider that, as judged from the data quoted by them, 'it is clear that India is not producing sufficient food for its present population'. After recording the opinion of Mr. Viswa Nath, Government Agricultural Chemist, that India's food production is at present sufficient for only two-thirds of her inhabitants, they conclude that there exists in India an 'exceptionally low standard of living accompanied by a general state of malnutrition'. They go on to say 'we cannot look with any degree of complacency on a population growing up to the margin of its food

supply and periodically suffering from the checks of famine and disease in order to keep below that margin '......' The true picture of India's population is that of a community living at an extremely low standard and growing at a pace which is outstripping or threatening to outstrip its food supply '.

As a remedy for this serious condition, Russell and Raja (1935) apparently advocate some method whereby the growth of the population may be checked artificially, but they do not appear to give any definite practical proposals as to how this is to be achieved, inside a reasonable period of time in a country like India.

'The remedy appears to us to lie in a wise combination of measures directed towards improvement in the standard of living and towards the regulation of numbers such as can be supported in comfort by the resources of the country'...... 'The success or failure of such effort depends largely on the voluntary acceptance by the individual of the measures proposed by the State. The solution of the population problem must, therefore, rest with the people themselves'.

While some limitation of, or check to, the increasing numbers of the population may possibly be desirable in the present state of this country, its aim should be the survival or production of a fitter race of people. Any measure which only results in the continuation of the present state of affairs, where, in some instances, two unfit men are needed to do the work of one healthy man, fails in its object.

While some system of 'birth control' might possibly be adopted by the more educated population, it must be remembered that, of the teeming masses of India, about 90 per cent live in rural areas and of these only about 8 per cent can either read or write. It seems improbable that a people in such a state of ignorance can be persuaded of the necessity for such control measures, nor are they likely to put them into practice, any more than has been found to be the case among the masses in many other more enlightened countries. It is possible that, when education has spread, some practical result may be observed after several generations. The difficulty of instituting any such measures would be especially felt in India, where the question of the deprivation of the hope of a family 'is well known on religious grounds to be one of the most trying afflictions which a Hindoo has to bear' (Taylor, 1870)*.

As it seems unlikely that any organised scheme of 'birth control' will have much effect in limiting the population growth rate of India for many decades, or possibly even for centuries, one must consider some of the other means whereby the pressure of population might be relieved, either naturally or artificially :—

(*i*) *Pestilence, famine and war.*—These are Nature's main methods for dealing with the problem of excess population, when migration is impossible. As one of the aims of modern civilisation is to diminish, as far as possible, the effects of these calamities, they cannot be looked upon as methods to be advocated as solutions for the problem of India.

It has been shown (Sinton, 1935) that malaria has a marked effect in retarding the natural increase of any population that is afflicted with this disease.

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* Among an agricultural population a numerous healthy family is a very valuable asset, for it helps to do away with the expense of employing labour. One is tempted to ask whether this ambition among the Hindu races did not originate in the necessity for an agricultural population to have children to help them to till their fields and produce food.

This effect occurs through its influence in increasing the death rate as well as in diminishing the birth rate. It might be suggested by some that the mortality from malaria is a beneficial action of Nature.

'Whether such "prunings" are not to some extent necessary to prevent an over-exuberant growth of the stock beyond the available means of subsistence, is a suggestion to which many would now be prepared to give a modified assent' (Young and Majid, 1930).

One of the aims in any plan for the restriction of population is that the residual individuals should produce a race of fewer but healthier persons. Unfortunately malaria does not always confine its attention to the weaklings, for many of the strong and otherwise healthy fall victims to its ravages. As has been pointed out by Sinton (1935*a*), in countries where this disease prevails, large numbers of the people belong to 'Class C3' in respect of their physical condition, apart from the detrimental effects of the disease upon their mental development and outlook.

(*ii*) *Extra-territorial expansion.*—This remedy might be achieved by purchase or by conquest. Neither of these appears likely to afford a solution of the Indian problem, even if it were possible in the former case, or desirable in the latter.

(*iii*) *External migration.*—This has been going on in a limited degree for many decades, but any permanent benefit produced by this action has been slight in proportion to the rate of growth of the population. With the tendency during recent years for other countries to restrict the amount of immigration permitted, it appears probable that permanent emigration will not prove a feasible solution of the problem of over-population in the near future, or, at best, will give but temporary relief.

By none of the above means does it appear practicable to meet fully the demands of an expanding population and the need for an increased and better food supply. One must consider, therefore, in how far the present potentialities of the country for an augmented food supply can be exploited to cater for the needs of the increasing masses, and to help in the amelioration of the condition of chronic malnutrition which some workers believe to be present among the population of India.

'My own concern has been mainly with nutrition; and my researches have led me to the conclusion that the diet of many millions of the Indian people is not such as can maintain physical efficiency and health. They are condemned from their mothers' wombs, to a subnormal or diseased existence as certainly as is the engine of the best motor car when not provided with efficient lubrication or when supplied with an improper fuel'....... 'Surely a matter of such moment is the concern of every person of education, influence or wealth; of every employer of labour; of every humanist' (McCarrison, quoted by the Public Health Commissioner with the Government of India, 1934).

According to Wattal (1934) the acreage under food crops per head of the total population in India has not shown any marked increase during the past three decades. It appears necessary, therefore, to meet the needs of the expanding population, and to counteract the evils of malnutrition among the present population, either (1) by an increase in the acreage under cultivation with foodstuffs, or (2) by improvements in agricultural methods, whereby the same acreage will give a higher yield, or a better type of foodstuff, or (*iii*) by augmenting the wealth of the country by industrialisation, or by some other increased development of her natural resources, whereby there will be a rise in

prosperity and individual wealth, and so the people will be able to afford the purchase of the needed additional food supply from abroad, as is the case in Great Britain at the present time or (*iv*) a combination of these methods.

(1) INCREASE IN THE ACREAGE UNDER CULTIVATION WITH FOODSTUFFS.

'Malarious regions are generally extremely fertile'....... 'The increase of malaria is an economic calamity which robs a country of its most precious source of wealth' (Jones, 1909).

Compared with agriculture, the other industries of India, though they play a useful part in the economic life of the country, are of minor importance in their present stage of development. 'In a country like India, no single factor in its prosperity can be so important as the increase of locally-grown food supply. Such an increase can be brought about by improved methods of agriculture, but also by bringing new areas under cultivation. In efforts to open up new areas of cultivation, again disease may often be a factor determining success or the reverse' (Christophers, 1924). As Sinton (1935*a*) has pointed out, malaria is probably the chief disease which hinders the expansion of agriculture in India, and so of an increase in her locally-grown supply of food.

India is not, however, the only country in which this vital need for an expansion of her cultivation has arisen in recent years, and in which malaria has acted as a serious obstacle to the development and successful exploitation of large areas of fertile land.

Twenty-five years ago, Howard (1909) pointed out that 'the loss to this country (the United States) in the way of retardation of the development of certain regions, owing to the presence of malaria, is extremely great. Certain territory containing the most fertile soil and capable of the highest agricultural productiveness is practically abandoned'......'These regions in the absence of malaria would have added millions upon millions to the wealth of the country'. Carter (1922), Fuchs (1922) and several other workers make similar statements. Since that time it has been found to be a paying proposition to reclaim much of these regions for the use of the nation, by measures which have had the effect of diminishing or controlling malarial prevalence (*vide* Sinton, 1936).

This problem is not confined to the malarious portions of the United States, but, as stated by Le Prince (1932), 'the other republics of America as well as ours have serious malaria problems which interfere with their normal development, with industrial development and agriculture'.

The need for an increase in her home-grown food supply has also been felt by Italy in recent years. In that country, there were large tracts of very fertile land which remained poorly cultivated, and sparsely inhabited, on account of the ravages of malaria.

'The industrial and agricultural development of Italy has been hindered in an incalculable degree by the prevalence of malaria in the southern half of the Italian peninsula, as well as in the valley of the Po and elsewhere' (Howard, 1909).

'Malaria in fact rendered vain, time and again, every attempt made to colonise the Roman Campagna and other districts' (Celli, 1933).

'Malaria always has been and still is one of the grave health problems of Italy. It is the chief barrier which has prevented the free movement of dense northern agricultural populations toward the rich deltas and sparsely inhabited plains of Sardinia and the south.

It is malaria that has until recently kept Rome itself from exploiting the well-watered and fertile Campagna at its gates, compelling the metropolis to obtain its milk from Milan and its vegetables from Naples' [Annual Report, Rockefeller Foundation, for 1934 (1935)].

With the natural growth of the population in Italy, and the restriction of emigration in recent years, the necessity for an increased local food supply has become a matter of vital importance. As a consequence, enormous schemes have been launched, chiefly within the last decade or so, to rid some of these fertile tracts of malaria, and thus not only to give an outlet for surplus population, but also to exploit to a greater degree the natural agricultural resources of the country. By this means it was hoped that not only would the prosperity of the country be benefited but the home-grown food supply be increased.

The result of this work has been described recently by Castellani (1933) —'During the last few years, however, thanks to the work of the new Government of Italy, in many parts of the country such as the Pontine region, the marshes have been conquered and malaria vanquished, and where fever, starvation and poverty reigned, well-tilled fertile fields are to be found populated by a healthy and happy people'. And this be it noted in a region which has been notoriously malarious for centuries, and which even 30 years ago was almost uninhabited because of the ravages of this disease.

In the Roman Campagna too, a marvellous change has taken place. The appalling state of this region at the beginning of the present century is described by Celli (1933)—

'In the Campagna both man and beast were struck by the disease (malaria) during the busiest periods of the year for agriculture, namely, in autumn and summer'....... 'Men were compelled to flee into the hills in order to save their lives—an expedient, which, however, did not always prove successful. A few pale ghosts of men remained, under the beating rays of the sun, to watch over the few wild beasts, which resisted the fever according to the law of the survival of the fittest'.

The present condition of this area is very different, as the result of anti-malarial and agricultural operations. 'Surely there cannot fail to come to any thoughtful observer the sense of change brought about, indeed, since the closing years of the past century, in the conditions of the Roman Campagna. There, among the ruins of many centuries of past civilization, we see the growth of healthy and flourishing newly-inhabited centres, factories, etc. This epoch of civilization will not be swept away as were its predecessors' (Celli, 1933).

To come nearer to India, in an official pamphlet issued by the Malayan Section of the British Empire Exhibition in 1924, malaria is given as 'one of the chief reasons why such large tracts of fertile land in Malaya remain sparsely populated and undeveloped'.

The need for an expansion of the locally-grown food supply in Malaya has recently been stressed by Williamson (1935) who describes how malaria is seriously hampering such expansion.

'What is of particular interest to agricultural organisers is that this (economic) loss (from malaria) falls mainly upon food production, depleted energies leading to diminished efficiency of cultivation; and, more than this, that the menace of malaria caused by felling jungle restricts the agricultural expansion normally needed by a growing population caused by immigration. But Malaya's need to expand her cultivated area is abnormal, and among Oriental countries unique, since she imports most of her foodstuffs'....... 'Malaya is one of the most malarious countries in the world, and her position is particularly serious, because, while she needs to grow much more of her food than at present, malaria exacts a heavy toll from the land already cultivated, and hems it in, and checks agricultural expansion' (Williamson, 1935).

As has been pointed out by Sinton (1935*a*), there are in India many large tracts of fertile land that have remained uncultivated or imperfectly cultivated, because of the prevalence of malaria. Many other areas also exist that were previously cultivated and have now become fallow, or returned to jungle, because of the ravages of this disease upon the colonists. There is no doubt that if these lands could be reclaimed and properly cultivated, they would form an outlet for some, at least, of the surplus population of India, would add to the supply of locally-grown foodstuffs, and would aid in the solution of the problem of malnutrition.

Attempts to colonise these fertile tracts must not be undertaken, however, without due consideration and proper preparation. The failure of attempts to reclaim such malarious localities, without taking proper precautions against this disease, has been recorded on innumerable occasions in many other tropical countries as well as in India.

A striking example has occurred recently in Palestine, where such a disaster was retrieved by scientific anti-malarial measures. In the scheme for the colonisation of Palestine after the war, the promoters first acquired swampy fertile tracts because these were the least populous and most readily bought. In addition they were well watered, and water is scarce in Palestine. The promoters were ignorant of the dangers of malaria, and the inevitable calamity happened. The colonies, in some instances, had to be kept going by annual replacement of settlers, and at some periods of the year more than half the working force was invalided. However, by the introduction of proper malaria-control measures, disaster was turned into success (Kligler, 1928).

'The colonizing agencies now realize that it is neither good economics nor sound practice to settle people in malarious areas unless provision is made to render these areas habitable. The land, they now realize, has to be rendered fit for colonization. It will not be long, it is hoped, until they come to the further wisdom of realizing that the land must be prepared before, and not after, the settlers arrive. The settlers themselves now recognize that it is a foolhardy, quixotic kind of martyrdom to succumb to malaria, and in two instances they have actually refused to settle in malarious areas unless the necessary preliminary work was done. In other words, malaria has been robbed of its mystic attributes, its inevitability; it has been revealed as a preventable—and often eradicable—disease' (Kligler, 1928).

The loss of the agricultural resources of such fertile lands is one of the heavy burdens that malaria imposes upon the people of India. While it may be admitted by some that the reclamation of many of these areas from the grip of malaria is not, at present, economically feasible, yet it appears highly probable that, before many generations have passed, it will be found that the exploitation of these regions for agricultural purposes will become a national economic necessity. Just as Italy has found in the case of her fertile malarious tracts, so will India find that it will pay her to control malaria in these areas, if she is to maintain her present position among nations, and attain to that prosperity and progress which she hopes to obtain through her new constitution.

(2) IMPROVEMENT IN THE METHODS AND INTENSITY OF AGRICULTURE.

'To the farmers it (malaria) may mean loss of crops from want of cultivation. It will always mean the non-cultivation or imperfect cultivation of thousands of acres of valuable land' (Howard, 1909).

'Agriculture is, and always will be, the great field of industrial activity, for upon it the welfare and prosperity of the large masses of India depend' (Hehir, 1927).

By improvement in the method of agriculture, one may hope to obtain not only a higher yield from the same acreage, but possibly also the successful introduction of new crops, which have a higher food or commercial value than those cultivated in the past.

It is possible that, by improved methods, an increase in the available food supply may be attained, but as pointed out by Christophers (1924)—

'Here (in India) are no capitalised communities of pioneer modern spirits imbued with a progressive modern outlook familiar with, and ready to utilise, the most recent forms of machinery and scientific invention. On the contrary, in the vast bulk of the population is the conservative spirit of those whose ancestors have always lived as they have'.

This unimaginative and unprogressive outlook among the rural and agricultural populations of India is very similar to that which has been described by Sinton (1935*a*) as being the result of malarial infection. In these circumstances, one is tempted to ask in how far this mentality is initiated and fostered, directly and indirectly, by the prevalence of malarial sickness, with which such a very large proportion of the inhabitants of these rural areas are, or have been, afflicted. What hope is there of awakening these people from their lethargy until the burden of malaria has been removed from them and from succeeding generations? Can their children ever hope, while so afflicted, to obtain the benefits and reap the rewards of that type of education which in modern days appears to be considered the panacea for all ills?

'I think the statement is true that a seriously malaria-ridden population is incapable, unaided, of maintaining a well-balanced health program. The obvious indication is to get rid of malaria first, put the community on a par with others which fortunately do not suffer from this handicap, and then proceed with normal development in affairs of health and of economic and cultural development' (Cumming, 1927).

Apart from this lack of initiative and this conservative spirit in relation to improvements in methods of agriculture, there is also the important fact that, even with the relatively primitive methods now in use, better results can seldom be obtained because of the effects of malaria upon the health of the agricultural worker (Sinton, 1935*a*). As pointed out many years ago by Craig (1909), 'It is invariably true that a people suffering from long-continued malarial infection are poor producers, especially along agricultural lines, where strength and endurance are demanded. It is a fact that will have to be taken into account in the endeavours to make this people (the Filipinos) prosperous, for I am convinced that malarial infection is very prevalent among them, often in an insidious form, and it offers a serious barrier to effort upon their part'.

The very serious effects which malaria has upon the efficiency of the agricultural worker have been discussed in detail by Sinton (1935*a*). The Royal Commission on Agriculture in India (1928) in their report have drawn attention to the harmful effects of malaria upon the output of work of the rural labourer in India, more especially in the United Provinces, Bengal and Burma. This Commission also emphasises the relationship between public health and agricultural prosperity. When one knows that malaria is the most prevalent disease of rural areas, and is the greatest cause of physical disability and labour inefficiency in malarious localities, the statements quoted below can be applied almost verbatim to malaria.

'The close relationship between agriculture and public health is obvious and the two react upon each other to a remarkable degree. Economic wastage due to disease cannot be over-exaggerated. Malaria slays its thousands and lowers the economic efficiency of hundreds of thousands; plague and cholera sweep the country from time to time; hookworm disease, kala-azar and diseases arising from diet deficiency insidiously reduce the labour power of the cultivating classes. Any enquiry, therefore, into the general condition of agriculture and the position of the cultivator must take account of the public health aspect of his life; of the suitability of his diet; of the sanitary conditions under which he lives and of his general rural environment. In order that, as a result of the "better farming" to which we hope our proposals will lead, the cultivator may have that "better living"* which should follow it, it is necessary to take stock of existing conditions and consider what steps are necessary to improve them. These conditions in the rural areas are certainly bad. Sanitation, in any accepted sense of the word, is practically non-existent'....... 'Enough has been said to show that the medical and public health authorities are fully alive to the problems which face them and are doing all that is possible with present resources to further medical relief and sanitation by curative or preventive measures. Release from the stranglehold of disease in which large areas of the country are at present gripped would enormously enhance its general prosperity. In the interests, therefore, of the community as a whole, no less than of the rural population which forms such an overwhelming part of it, we would emphasise the urgency of the need of developing the rural medical and public health services to the utmost possible extent and with the utmost speed. We would impress, both on the Government of India and on local governments, our most earnest conviction that assistance to these services and to all unofficial efforts of proved merit should be given without stint of men or money. We feel confident, from the steps already taken by the Government of India and the provincial governments, that this recommendation will receive their sympathetic consideration' (Royal Commission on Agriculture in India, 1928).

The Royal Commission on Labour in India (1931) also points out the damaging effects of malaria upon the efficiency of workers in rural areas in India.

There is, therefore, very strong evidence to support the view that malaria, through the physical and mental disability produced, is one of the greatest, and probably the greatest, of the obstacles which stand in the way of improvements in agriculture in India, and so of an increase in the quantity and quality of her food supply. There seems little hope of any great or satisfactory advance in this direction, so long as the rural populations continue to bear this enormous burden of malarial sickness, that is sapping both their physical and mental activities. As remarked by Johnson (1926)—'The labor cost is from 40 to 50 per cent of the total cost of production on a plantation. Why study fertilizers, seeds, tools, and markets and forget the health of your labor element—without which all other elements are useless?'†

Cilento (1928) has made an extensive investigation into the causes of depopulation in the Western Islands of the Territory of New Guinea. The results show very clearly the influence of malaria in producing depopulation and

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* This would in practice be equivalent to what the Italians have termed 'bonification' in their campaign against malaria. In this no single measure is used, but efforts are made to raise at the same time not only the agricultural condition but also the sanitary, social and economic ones of the population. Where such measures have been properly combined, the scourge of malaria has been markedly ameliorated, or even almost eradicated in some localities. Some of the factors influencing this result have been discussed by Sinton (1933).

† The *Hindustan Times* (Delhi), in its issue of 23rd September, 1934, gives the comparative average yield of rice per acre as 5,700 lbs. in Spain, 2,100 lbs. in Japan, 3,300 lbs. in Italy and only 890 lbs. in India. While this poor yield in India may be due, to a great extent, to different and less efficient methods of agriculture, or unsuitable soils, one is tempted to ask in how far is this backward state of affairs due to lack of enterprise and diminished labour efficiency resulting from the action of malarial sickness upon both the minds and bodies of the inhabitants of India.

agricultural decline, with resultant poverty and malnutrition. 'With this continued invasion of unknown and deadly diseases, under the constant handicap of an insufficient and hardly won diet—for who could forage when every young and able-bodied villager had been carried off—it is hardly to be wondered at that the unfortunate remainder sunk into that condition of hopeless lethargy, which is to-day, over a score of years later, imputed to them as a comprehensive reproach '*.

The various factors concerned in the depopulation have been discussed by Cilento (1928), who concludes—

'These are referable finally to two interacting factors, namely, malaria and food deficiency, which together constitute a vicious circle of decline. Malaria and such chronic diseases produce a lethargy and bodily weariness* which prevents anything but the most essential tilling of the soil and foraging for food, while the very poverty of diet that results lowers the resistance to disease, and so permits more frequent disease, with constantly lesser food supplies, until the point is reached at which the human organism can no longer cope with the situation'.

Such a condition of deficient diet gives rise to effects which closely resemble many of those which are caused directly by malaria (*vide* Sinton, 1935, 1935*a*).

'It (deficient diet) is one of the causes of inferiority in physical development, instability of the nervous system, lack of recuperative power and endurance and consequent cumulative fatigue, and lack of resistance to infections such as tuberculosis and other types where specific immunity is not easily developed by the body. In addition to these, the rate of development of senile characteristics and consequently the length of the span of life are greatly influenced by the type of diet to which one adheres' (McCollum and Simmonds, 1925).

'It is apt to be forgotten that the well-being of a people depends more on proper nutrition and efficient sanitation than on aught else. The proper nutrition of her people, the adjustment of the food supply to the population and of the population to the food supply, the provision of efficient sanitation in her towns and villages: these are India's needs; all else is of secondary importance' (McCarrison, quoted by the Public Health Commissioner with the Government of India, 1934).

Cilento (1928) instances one island where 'the cumulative effects of these diseases (malaria, frambœsia and ankylostomiasis) have lowered the resistance to a degree that has outweighed the advantages of a better diet'. So it is seen that the mere provision of better nutrition will not always counteract the evils of a disease like malaria, if it be severe, unless combined with other measures which diminish the latter.

It is concluded by Cilento (1928) that 'it is demonstrated that the depopulation of the Western Islands is almost entirely a medical matter'. He discusses a campaign against this evil and says 'co-operation between the medical and agricultural aspects of this complex problem is essential for its success'.

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*'The psychological depression found among native groups is as obviously a consequence of sickness and undernutrition, as are the lack of initiative, the lack of vigour, and the despair found among white races in similar circumstances of ill health, poverty and privation'...... 'It becomes only too apparent that the attitude of "hopelessness and helplessness" upon which such stress is laid, is, itself, directly proportional to the degree of local disease prevalence. It arises as a direct sequel of it, and is not a primary condition' (Cilento, 1928). This is the same stigma of 'laziness' which has also been laid upon malaria-stricken people in other parts of the world.

The very close relationship between malarial prevalence and agricultural decline in the province of Bengal has been described in great detail by Bentley (1925), and Sinton (1935*a*) has discussed the problem in connection with other parts of India.

The introduction of improved methods of agriculture in many parts of India, without accompanying measures to ameliorate malarial sickness, may enrich those people who have the capital and the initiative to undertake these steps, if sufficient cheap, efficient and easily available labour be obtainable. These will be mainly the proprietor who can protect himself and his family from the dangers of this disease, or the 'absentee landlord', who lives in a more salubrious climate. It is highly improbable that such measures will have a marked effect in bettering permanently the conditions of the bulk of the malaria-ridden rural working population, the majority of whom have neither the health, the capital, nor the initiative that are needed to carry out such improvements successfully, while oppressed by the multiple burdens imposed by malaria. If such agricultural improvements are to confer a real and permanent benefit on the masses of India, and not only upon a favoured few*, it is essential that the malaria problem of rural areas be tackled at the same time and with equal vigour—a development of 'the rural medical and public health services to the utmost possible extent and with the utmost speed', as advocated by the Royal Commission on Agriculture in India (1928).

(3) AUGMENTATION OF NATIONAL WEALTH BY INDUSTRIALISATION AND BY INCREASED DEVELOPMENT OF NATURAL RESOURCES.

'All malarious countries are seriously handicapped and their natural development towards the highest economic, industrial and political efficiency is materially retarded by malaria'..... 'Malaria has been one of the greatest foes of civilization; its operations for evil have continued from century to century. Gigantic commercial enterprises, undertaken at different times, have been abandoned on account of the terrible havoc wrought by malaria' (Hehir, 1927).

'There is no doubt, however, that malaria exercises a disastrous influence on the economic life of nations and individuals' (Celli, 1933).

If industrialisation could be started on a large scale in India, and if a greater development of her natural resources were successfully undertaken, these would give employment to large numbers of her immense population. At the same time, the increase in the national wealth, produced by such measures, would enable her to augment her food supplies by purchase from abroad, as is done in many other countries. Such a solution would, however, probably be only a temporary one, for in the long run the expansion of population in the world is limited by the amount of food which can be produced.

Unfortunately, as discussed by Sinton (1935*a*), such schemes of expansion, industrial and otherwise, may be seriously hampered by the prevalence of malaria among the labour forces needed for such work. As remarked by Christophers (1924)—

'Next to the production of food supply in importance to India is the expansion of her industries. Industrial success is largely bound up in the maintenance of effective labour forces, and the factor which determines the satisfactory maintenance of a labour force more than any other is the prevalence of disease. It is the aim of industrial concerns to have a labour force living

* As James pertinently remarks 'no policy can be considered entirely satisfactory that aims at the protection of only a few, however important these few may be, while it leaves the bulk of the inhabitants of a place in the same condition' (Balfour and Scott, 1924).

happily on or near the estate. Very often on account of disease, such communities have to be maintained by constant recruitment, the children die, the adults, except such as weather the storm and become old immune hands, suffer from fever and anæmia and the mental consequences of such a state, and the net result is disease and a deficient and ineffective labour force. In such industries also as employ mill-hands, the influence of disease must be ever present reducing efficiency, increasing cost of wages and limiting prosperity. We may say that in the matter of industry, disease is not only a tax, but to some unknown extent, depending on the industry concerned, a limiting factor to its full and useful development'. As has been pointed out by Sinton (1935*a*, 1936) the disease which appears to have the greatest influence upon the present and future of industries in India is malaria.

The Royal Commission on Labour in India (1931) also say that 'during our tours we could not fail to be impressed with the tremendous importance of malaria in connection with the health of the industrial worker'.

'Let us assume that in one of these progressive countries a group of bankers and prominent business men started to develop a plant to manufacture structural steel or some other important industry. If imported skilled labor should be used, then unless the directors of the industry take adequate precautions, it will not be long before the workmen become infected (with malaria), become inefficient: the operation costs climb out of all proportion to what they should be, skilled labor may have to be temporarily replaced by unskilled labor, accidents may follow and financial difficulty will follow much quicker than is anticipated' (Le Prince, 1932).

Many business men have now realised that the control or amelioration of malaria among their staff and workmen is a paying proposition, and have considered money spent in this way to be a sound commercial investment (Sinton, 1936).

'Individuals and groups are notoriously slow in applying to themselves the knowledge that has been gained of preventive medicine. But industrial organisations and business concerns, looking at the subject from an entirely different angle, have been quick to see the importance of protecting the health of their employees as a business proposition solely. They have been told that malaria, through sickness and decreased efficiency, causes a greater economic loss to the malarious sections of the South (of the U. S. A.) than all the other preventable diseases combined'....... 'This awakening of the Southern commercial interests from a purely business standpoint may not be prompted by what some would term the highest motives, but it is backed by shrewd business sense' (Fricks, 1920).

From the evidence available, it is clear that any attempt at industrialisation on a large scale in India will, sooner rather than later, depend for its success upon the malaria problem, which as remarked by Watson (1921) is the labour problem in the tropics, and 'the solution of the malaria problem will also be the solution of the labour problem'.

As has been emphasised by Sinton (1935*a*), the retarded development of the natural resources of India is due mainly to the ravages of malaria upon the labourers and staff employed in such work. This disease hinders the development of mineral wealth and of forest resources, of railway expansion and many other enterprises, as the successful result of which the wealth and prosperity of India could be enormously increased.

From the evidence available it appears clear that the successful augmentation of the national wealth and prosperity of India, whether by large scale industrialisation or by increased development of her natural resources, cannot hope to attain any high degree of permanent success, unless they are supported

by measures producing a diminution in the malarial sickness and disability among the labour forces employed.

SUMMARY.

It has been pointed out that the provision of greater facilities for the employment of the large masses of population in India, and of a sufficient supply of suitable food for these people, form some of the most urgent problems which India must face in the future, if she does not already face them.

The solution of these problems would appear to depend largely upon (1) an increase in the acreage under cultivation with foodstuffs, (2) an improvement in the methods and intensity of agriculture, and (3) an augmentation of the national wealth by industrialisation and by an increased development of the natural resources of the country, or (4) a combination of these methods.

It has been shown that the success of any steps taken to implement such measures of improvement in the national conditions, will be largely influenced by the measures which are taken to control the incidence of disease, predominantly malarial in origin, among the population.

If India be, at present, in such a parlous state of over-population and deficient food supply, and her people in such a state of chronic malnutrition, as some economists believe, then there can be little doubt that it would be a paying proposition for India to take much more active measures to ameliorate the ravages of malaria, if she cannot control them. Even if one be not agreed that affairs have already reached this alarming stage, there is little doubt that they are tending rapidly in that direction, and that it would pay India to commence a more intensive anti-malarial campaign before conditions become more

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*The results, it is hoped to attain, might possibly be expressed in the words which Goethe put in the mouth of Faust—

'A marsh spreads at the mountain's foot, and poisons all that has already been won. To drain that pestilential fen would be the last and greatest victory. Wide lands I would open up for millions upon millions of men, lands where they could dwell, not in entire security perhaps, yet active and free, amid green fruitful fields—men and their herds, content upon the new-won land, sheltering under the lea of the sea-wall which industrious hands have built. Here, shrined within, a land of paradise; there, let the stream without roar headlong to the verge. But if it threatens to break in, all alike will speed to close the gap. Yes, that thought absorbs my being; that is the final word of wisdom: he alone is worthy of liberty and of life who must win them anew day by day. Here, girt with peril, in childhood, in manhood, in old age, he strives and toils as the years pass. Would I might see that teeming host, and stand amid a free people in a free land'.

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Records of the Malaria Survey of India, 6, 1, March, 1936.

DESCRIPTION OF *ANOPHELES (ANOPHELES) HABIBI* N.SP. FROM QUETTA, BALUCHISTAN.

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[13th January, 1936.]

WHILE carrying out a malaria survey of Quetta, Baluchistan, from July to October 1935, two specimens of an anopheline mosquito with unspotted wings were encountered. One of these was captured as an adult in the village of Hudda on 1st August, 1935, and the other was bred from a larva collected from an irrigation channel on 14th September, 1935. Both specimens were females and, although identical with one another, they appeared to be distinct from any species of anopheline mosquito with unspotted wings so far recorded from the Indian area, including Baluchistan. The rarity of this species in the Quetta area, during the period of the survey, is indicated by the finding of only two specimens out of over 14,000 anophelines identified from this locality.

Among the anophelines of Quetta, the Mediterranean element as well as the Oriental and the Indian elements are represented. It was thought, therefore, that the two specimens encountered with unspotted wings might prove to be identical with one of the species recorded from the Mediterranean area. On further investigation it was found that these two unidentified anophelines from Quetta showed a closer resemblance to *A. claviger* Meigen (*A. bifurcatus* Meigen, 1818), and to *A. sacharovi* Favr, 1903 (*A. elutus* Edwards, 1921), than to any other species. They differed, however, in certain morphological details, from the specimens of these species which were available for study in the

collection of the Malaria Survey of India*, as well as from the published descriptions of these species. These differences appear to us to be sufficiently distinct to warrant the creation of a new species.

The name *habibi* has been given to this species as, by a curious coincidence, the adult specimen was captured by Insect Collector Habib from the village of Hudda which is situated on the banks of the Habib Nullah, a well-known landmark in Quetta. A detailed account of the morphological characters of *A. habibi* has been given below, thus bringing the description of this species into line with those already given for the other Indian anophelines by Christophers (1933).

DESCRIPTION OF *ANOPHELES (ANOPHELES) HABIBI* N.SP.

1. CHIEF DIAGNOSTIC CHARACTERS.

The chief diagnostic characters of *A. habibi* may be summarised as follow :—

(*a*) *Wing*.—(*i*) Unspotted, without any pale markings except on the outer one-third of the costa, which shows a pale golden flavescence.

(*ii*) Length of the anterior forked cell about equal to that of the petiole.

(*b*) *Mesonotum*.—More or less uniform golden brown in colour, with only a suspicion of darker lateral areas; chætæ on median region arranged in three longitudinal areas.

(*c*) *Frontal tuft*.—Rather poorly developed, and of a creamy white colour.

2. DETAILED DESCRIPTION

Female.

A moderately large mosquito (length of wing 4·6 mm. in type, and 4·0 mm. in the paratype specimen). General coloration light brown.

Head with interocular vertex triangular; scales over the occiput of the usual anopheline character, forming a pronounced pale vertical spot; head scales fairly broad (breadth index 6·3), with 11—15 striations which extend to about three-fourths the length of the scale; vertical chætæ pale cream, 5 in number (two on one side, three on the other); ocular scales forming a dense white area; anterior portion of interocular space with some white fusiform scales (with 7 striations), and a few (6-7) elongated curved creamy scales; frontal tuft rather poorly developed (Plate II, fig. 3) and general coloration creamy white; ocular chætæ dark, as usual in anophelines. *Antennae* with only a few dark scales on the inner surface of the torus; a small inconspicuous cluster of mixed dark and pale scales present on the first flagellar segment mostly on the internal surface; remaining segments apparently without scales. *Palpi* rather long and slender (2·24 mm. in length), a trifle shorter than the proboscis (Plate II, figs. 2 and 3), 1·4 of thorax and 0·5 of wing; the five segments, commencing with the rudimentary basal one, measure 0·03, 0·34, 0·37, 0·17, and 0·087 of the whole

* The specimens of *A. claviger* studied came from England, Italy and Spain, while those of *A. sacharovi* came from Mesopotamia.

organ; palpal index 0·5. The whole organ is sparsely covered with scales, those on the basal rudimentary and on the 2nd segment semi-erect, while those on the other segments somewhat appressed. The whole organ pale brown in colour without any pale markings, appearing a faint golden brown in certain lights. Apical segment slightly swollen giving a suggestion of clubbing, with a cluster of dark hairs at the tip. *Proboscis* 2·5 mm. long; uniformly pale brown, the whole appearing flavescent in certain lights.

Thorax: Anterior pronotal lobe with a few pale hairs only. Propleural hairs 6-7. *Mesonotum* more or less unicolorous, golden brown with the lateral areas a trifle darker, while the median area in certain lights shows two faint narrow lines with greyish dusting; median region covered with pale golden hairs arranged in three broad areas (Plate II, fig. 1) which merge into one another posteriorly, about the level of the wing-roots; scales absent except for a cluster of white hair-like scales on the anterior promontory; lateral areas (and fossæ) bare except for a number of scattered long dark chætæ and pale hairs, the latter present only near the outer margins. Scutellum with dark chætæ and pale hairs (most of the former broken in the type specimen, but present in the paratype). Pleuræ pale yellow, without any scales; spiracular bristles 3-4; prealar 3-4; upper sternopleural bristles 2 long dark and 3 short pale golden, while lower 6 pale golden, forming two separate clusters; upper mesepimeral arising in a cluster of 15 pale golden hairs.

Wings: Anterior forked cell about half as long as petiole (1: 0.55), measuring about 0 28 length of wing (Plate II, fig. 4), its base being slightly nearer wing-base than that of the posterior forked cell; forked cell index 1 77 in the type, and 1·73 in the paratype specimen. Wing veins rather lightly scaled; *lateral scales* rather long with tendency to have pointed ends, 0 1—0·11 mm. long, breadth index 10, striations 4-5; *median scales* for the most part about 0 055 mm. in length, breadth index 8-9, striations 3-4. Wing almost entirely devoid of pale markings, except the distal third of the costa, which shows pale golden flavescence (very pronounced in certain lights); the colour of the wings is dark grey. In the specimen bred out in the laboratory (paratype) the distal third of the costa is not, however, golden*.

Legs: General coloration brownish black appearing pale brown in certain lights; femora not swollen in the basal half, cylindrical, anterior and dorsal surface dark nearly to base, but pale posteriorly throughout their length; a faint knee-spot present on all the legs; tibiæ and tarsi entirely dark; coxæ noticeably pale, with scattered pale hairs; trochanters with some hairs and a few dark scales on the posterior surface.

Abdomen: Brownish, with pale golden hairs, and devoid of scales even on cerci.

The female only is available for study. The type specimen, collected as an adult from Hudda village, Quetta, has been sent to the British Museum. The paratype specimen, reared from the larval stage, has been preserved in the collection of the Malaria Survey of India, Kasauli.

* A possible explanation for this difference between the type and the paratype specimens is that the latter was pinned shortly after emergence from the pupa, and there may not have been a sufficient time interval for the colour to develop.

3. POINTS BY WHICH *A. HABIBI* MAY BE DIFFERENTIATED FROM OTHER SPECIES WITH UNSPOTTED WINGS BELONGING TO THE SUBGENUS *ANOPHELES* FOUND IN THE MEDITERRANEAN AND ORIENTAL REGIONS.

A. FROM INDIAN SPECIES OF *Anopheles* WITH UNSPOTTED WINGS.

(*i*) *A. aitkeni.* *A. insulaeflorum.* *A. pinjaurensis.* — These three species are characterised by having narrow scales on the occiput, whereas *A. habibi* has broad scales of the usual anopheline type on the occiput.

(*ii*) *A. culiciformis.* *A. sintoni.* — In these two species the head scales are all sooty black whereas in *A. habibi* there is a well-marked spot of pale scales on the vertex. *A. habibi* also differs from these species by having a cluster of white hair-like scales on the anterior promontory of the mesonotum.

(*iii*) *A. barianensis.* — The following characters of *A. habibi* serve to distinguish it from *A. barianensis* :—
- (*a*) poorly developed frontal tuft.
- (*b*) absence of median line of milk-white scales on the anterior one-third of mesonotum.
- (*c*) knee-spot much less distinct than in *barianensis*.

B. FROM MEDITERRANEAN SPECIES OF *Anopheles* WITH UNSPOTTED WINGS.

(*i*) *A. claviger.* — The following characters of *A. habibi* serve to distinguish it from *A. claviger* :—
- (*a*) distinctive coloration of mesonotum, *i.e.*, more or less unicolorous, golden brown.
- (*b*) the relative length of the petiole.
- (*c*) the flavescent distal one-third of the costa.

(*ii*) *A. plumbeus.* — *A. habibi* is readily distinguished from *A. plumbeus* by having :—
- (*a*) a poorly developed frontal tuft.
- (*b*) no median line of milk-white scales on the anterior one-third of the mesonotum.

(*iii*) *A. maculipennis.* *A. sacharovi.* — *A. habibi* is distinguished from these two species by the absence of dark spots, formed by clusters of scales, on the wingfield.

In general appearance *A. habibi* closely resembles *A. sacharovi,* but besides the absence of dark spots on the wingfield of the former, there is a difference in the arrangement of the hairs on the mesonotum. In *A. habibi* the pale golden hairs on the middle region of the mesonotum are arranged in three well-defined longitudinal areas (Plate II, fig. 1), while in *A. sacharovi* they are irregularly distributed.

(*iv*) *A. algeriensis.* *A. algeriensis* var. *turkestani**.	From this species and its variety, *A. habibi* is differentiated by having broad scales on the occiput such as are usual in anophelines. In *algeriensis* and var. *turkestani* the scales on the occiput are narrow.

4. BIONOMICS OF *A. HABIBI.*

Little can be said with regard to the bionomics of *A. habibi.*

(*a*) *Adult.*—The only specimen of *A. habibi* captured as an adult was collected from the ruined village of Hudda, Quetta, on 1st August, 1935, two months after a severe earthquake. Adult anophelines were collected from crudely constructed shelters erected by the earthquake refugees, and in one of these *A. habibi* was captured. On this occasion the adult catch included the following species of anophelines :—

A. superpictus, *A. dthali* } Mediterranean element.
A. culicifacies, *A. stephensi* } Indian element.
A. habibi.

(*b*) *Larva.*—Only one specimen of *A. habibi* was reared from the larval stage in the laboratory. This larva was collected from a small irrigation channel arising from an artesian well in the vicinity of Galbraith Spinney near Quetta, on 14th September, 1935. The flow of water was almost imperceptible, and the channel was overgrown with grass and weeds, rich in *Spirogyra,* and partially shaded by trees. Other species of anophelines recovered at the same time, and from the same place, included :—

A. culicifacies, *A. stephensi* } Indian element.
A. superpictus Mediterranean element.

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*No *detailed* description of this variety appears to have been given. It was originally described as a variety of *A. algeriensis,* but has subsequently been placed as a variety of *A. claviger* by Khodukin (1928). From the description given by Schingarew (1926), it would appear to differ from the latter species, however, in the character of the scales on the occiput which are narrow as in *algeriensis.*

Explanation of Plate II.

Anopheles (*Anopheles*) *habibi* n. sp.

Figure 1. Dorsal view of head and thorax (part) of type specimen, showing the pale *vertical spot* and the arrangement of the chætæ on the median region of the mesonotum.

S—A longitudinal fracture of the thorax caused by the insertion of the pin at the time of mounting.

„ 2. Dorsal view of the head of the type specimen. (Proboscis being out of focus appears shorter than the palps).

„ 3. Lateral view of the head of the type specimen showing the frontal tuft, and the length of the palps in relation to the proboscis.

„ 4. Wing of the paratype specimen, slightly retouched to indicate the position of the flavescent area (*F*) on the costa.

PLATE II

Records of the Malaria Survey of India, 6, 1, *March,* 1936.

TRANSPORT AND CONTROL OF *AEDES AEGYPTI* IN AEROPLANES.

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[13th January, 1936.]

THE increase of air traffic has drawn attention to the possibility that yellow fever may be carried to India by infected mosquitoes travelling in aeroplanes. This paper records certain observations made to determine

(1) the time and distance for which *Aedes aegypti* will survive carriage in aeroplanes,
(2) the frequency with which they travel under natural conditions,
(3) the effect of altitude,
(4) practical methods by which they may be destroyed in aeroplanes, and
(5) methods of mosquito-proofing aeroplanes.

1. SURVIVAL IN AEROPLANES IN FLIGHT.

At Karachi Air Port cages of mosquitoes were handed to the First Officers of air liners, who were requested to note the number dead each day. The mosquitoes were female *Aedes aegypti* which had taken a blood meal immediately before starting the journey. A raisin was placed in the cage for refreshment *en route*. A similar cage of mosquitoes was retained as a control.

Owing to their other duties, the officers were not always able to keep a complete record, but the results returned by them are of definite value. Between the 30th June and the 31st July, 1935, five batches of mosquitoes were despatched by Imperial Airways liners of the 'Hannibal' class. There were two cages in each batch, of which one was placed in the forward baggage compartment or in

the pilots' cockpit, and the other was tied to the cross-bracing wires inside the rear end of the fuselage, about 24 feet behind the cabin. In all, 56 mosquitoes were sent off. Most reached Sharjah alive at the end of the first day, but all died before Baghdad, 36 hours' journey from Karachi. The maximum altitudes of the journeys were between 6,000 and 8,000 feet. Of eighteen control mosquitoes, fifteen survived for forty-eight hours or more.

A pyrethrum spray is used as a routine in the cabins of all Imperial Airways liners. It was hoped that the spray would not affect mosquitoes placed in the baggage compartment or in the pilots' cockpit, but it may perhaps have been the cause of the early mortality. It is however improbable that pyrethrum extract diffused in the cabin could have reached the extreme rear end of the fuselage, which is freely ventilated. Possibly the mosquitoes were unable to withstand the draught.

During August the mosquitoes were sent in the Dutch K. L. M. liners of the 'Douglas' type. A cage of twelve mosquitoes was placed in each machine. Of the first thirty-six mosquitoes, thirty reached Amsterdam alive, many returned to Cairo, and two passed through Karachi to reach Jodhpur on the return journey before they died. Of another batch of twelve, 'several' reached Amsterdam and returned alive to Baghdad. Corresponding to these forty-eight mosquitoes were forty-five controls. Of these, 44 lived for four days, 43 for six days, and 42 for seven days. The distances and times were

to Amsterdam	4,599 miles	2½ days.
to Cairo on the return journey ..	6,809 „	5 „
to Jodhpur „ „ „ ..	9,580 „	6½ „

It would have been better to release stained mosquitoes in the cabin rather than to enclose them in cages, but the operating companies were unwilling to allow this. It is doubtful if the cages gave any protection. On the other hand they prevented the mosquitoes from taking a blood meal and from choosing the resting places most acceptable to themselves.

These records show that female *Aedes aegypti* survived long aeroplane journeys in Europe and the Near East, but they do not prove that, if free, they would not have left the aeroplane during the journey.

Similar experiments have been carried out in Central America and the Belgian Congo, the records of which are summarised in Table I.

During the journey the aeroplanes in the American experiments made several landings and generally one or more night stops, when passengers and baggage were embarked and disembarked. The mosquitoes were free to leave the machine, yet a proportion was recaptured at the end of the journey. The proportion would undoubtedly have been higher but for two considerations. Firstly, it is not to be expected that all the mosquitoes present in an aeroplane will be detected and captured, and secondly, in several aeroplanes, the mosquitoes became so troublesome that an insecticidal spray was turned on them. In one machine (Experiment 6 of Table I) in which it was known that no spray was used, 21, or 35 per cent, of 60 mosquitoes liberated were caught.

In Experiment 10 of Table I, none of the *Mansonioides* survived the journey. Trolli (1932) suggests that the mortality may have been due to shocks on landing or to the length and altitude of the journey. The cage of mosquitoes was placed in the aeroplane on the evening of the 8th February,

TABLE I.

Summary of published data on the survival of mosquitoes in aeroplanes.

Reference		Journey.	Number of aeroplanes.	Total number of mosquitoes.	Percentage found alive at destination.	Approx. hours journey.	Night stops.	
Griffitts and Griffitts, 1931	1	San Juan (Porto Rico) to Miami (Florida).	1	40	10 or more	?	0	Stained *Aedes aegypti* liberated in aeroplanes.
	2	Ditto.	1	30	10	10	0	Ditto.
	3	Ditto	1	?	6 in number	10	0	Ditto.
Griffitts, 1933 ..	4	San Salvador (C America) to Brownsville (Texas).	12	840	8	30	1	Ditto.
	5	San Salvador (C America) to Miami.	1	70	6	80	3	Ditto.
	6	Cristobal (Canal Zone) to Miami	15	840	10	34	1	Ditto.
	7	Cristobal (Canal Zone) to Brownsville.	30	1,610	2	55	2	Ditto.
McMullen, 1933	8	Cristobal to Miami ..	1	70	3	?	1	Ditto.
Trolli, 1932 ..	9	Coquilhatville to Léopoldville (Belgian Congo)	1	?	Majority	6	0	*Mansonioides* in cages.
	10	Léopoldville to Élisabethville (Belgian Congo).	1	?	0	15	1	Ditto.

the journey was on the 9th and 10th and the cage was examined on the 11th. It is therefore possible that the mosquitoes died of starvation and exposure.

The above is the evidence for the persistence of *Aedes aegypti* in aeroplanes in flight when introduced artificially. It does not show the extent to which they will voluntarily invade aeroplanes under natural conditions.

2. NATURAL PREVALENCE OF MOSQUITOES IN AEROPLANES.

The frequency with which mosquitoes travel voluntarily may be estimated from the results of searching aeroplanes at the end of a journey.

Between the 15th June and the 31st October, 1935, air liners arriving at Karachi Air Port were searched by us. The aeroplanes were the 'Atalanta' 10-seater and 'Hannibal' 28-seater classes of Imperial Airways, the 'Douglas' 11-seater class of K. L. M. and the three-engined 6-seater monoplanes of Air France. In all cases the cabins and baggage compartments were examined, and where possible, the rear end of the fuselage behind the cabin. A torch, test tubes and a net were carried to catch mosquitoes. These aeroplanes had either travelled across India from the east, or had arrived from Egypt or Damascus. In all 106 machines were searched, but no mosquitoes were caught. On one occasion a mosquito was seen, but could not be caught before the departure of the aeroplane. It appeared to be a *Stegomyia,* and was seen in a 'Douglas' machine which had spent the previous night at Jodhpur.

Unfortunately there is no definite evidence of the prevalence of mosquitoes at the aerodromes from which these aeroplanes had arrived. However, passengers and crews agreed in saying that they had not been troubled by mosquitoes at Baghdad, Jask, Sharjah or Jodhpur, and that they had not needed mosquito-nets. Perhaps the only reason for our failure to find mosquitoes was that there had been none to invade the machines at the ports of departure.

Similar searches have been made in other countries, the results of which are summarised in Table II.

To estimate with accuracy the natural tendency of mosquitoes to travel in aeroplanes, it is necessary to know the prevalence of mosquitoes at the aerodrome of departure, to have a record of the number of aeroplanes searched, and to be certain that an insecticidal spray has not been used. The summary in Table II does not fulfil these conditions. In many cases an insecticidal spray was used by the crew. It must have reduced the number of mosquitoes, but the evidence in Table II does not show the extent of the reduction. It does however show that a large number of aeroplanes have been searched, and that a few Anophelines and Culicines and one male *Aedes aegypti* have been caught.

3. EFFECTS OF REDUCED ATMOSPHERIC PRESSURE.

Since the respiratory mechanism of insects is simpler than that of man, it might be expected to respond less efficiently to changes of atmospheric pressure. There is reason to believe that the oxygen in the tracheoles is renewed by diffusion, and that the difference in partial pressure between the exterior and the tracheoles is sufficient to supply the needs of the insect (Wigglesworth, 1934). A sudden reduction of atmospheric pressure might therefore cause a breakdown of the mechanism.

TABLE II.

Summary of published data on the results of searching aeroplanes for mosquitoes.

Reference.	Place of search.	Origin of aeroplane.	Number of aeroplanes searched.	Mosquitoes captured.			
				A. aegypti	Anophelines.	Culicines.	Spray used.
Griffitts and Griffitts, 1931.	Miami ..	Central America ..	102	1 male	0	28	Sometimes.
Trolli, 1932 .	Léopoldville ..	Belgian Congo ..	17	0	0	0	?
	Coquilhatville ..	„ „	Several	0	0	10	?
	Basankasu ..	„ „	4	0	0	0	?
	Inongo ..	„ „	?	0	0	0	?
	Élisabethville ..	„ „	?	0	0	0	?
Crouch, 1935 ..	Khartoum ..	Egypt, E. Africa ..	350	0	2	1	Yes.
Black, 1935 ..	Entebbe ..	Sudan . ..	12 months	0	13	13	Probably.
Aldridge and Hunt, 1935.	Juba ..	Uganda, Malakal	151	0	Occasionally found*		Yes.
Symes, 1935 ..	Kisumu .	Sudan	25	0	53	73	No.
	„ ..	Sudan, Tanganyika .	104	0	9	10	Sometimes.
	Nairobi ..	„ „	67	0	10	2	Sometimes.

*Twelve aeroplanes only found to be infested. The number of mosquitoes in each was usually one or two; on one occasion eleven.

For our experiments the Aircraft Inspection Department at Karachi lent the apparatus which they use for testing altimeters. It consists of two glass-fronted chambers, which are connected and can be exhausted simultaneously by a pump. The mosquitoes were enclosed in a glass tube closed with mosquito-netting, and could therefore be watched. The mosquitoes were *Aedes aegypti* hatched in the laboratory. The females were fully fed before the test. An altimeter was placed in one chamber and the specimen tube with mosquitoes in the other; both chambers were exhausted, and the change of pressure was recorded as the change of altitude shown by the altimeter in the second chamber. Further details are shown in Table III.

TABLE III.

Effect on Ædes ægypti *of change in atmospheric pressure.*

Number.	Mosquitoes.	Altitude.	Time of ascent.	Time at top.	Time of descent.
1	6 females	5,000 ft.	30 minutes	1 minute	30 minutes
2	1 female	5,000 „	25 seconds	3 minutes	10 seconds
3	1 „	10,000 „	50 „	3 „	12 „
4	2 females	10,000 „	10 minutes	1 hour	10 minutes
5	4 males	10,000 „	10 „	3 hours	10 „

In Experiment 4 the mosquitoes seemed more sluggish and were perhaps less willing to fly when the apparatus was shaken. In the others, no effect at all was seen, even when the ascent and descent were as rapid as in Experiments 2 and 3. In all cases the mosquitoes appeared normal on the following day. We were unable to conduct further experiments as the apparatus was required elsewhere.

The conditions of these experiments are not exactly the same as those in an aeroplane, for change of altitude involves change of temperature. Moreover, a longer exposure to reduced pressure might have produced some degree of asphyxiation. It has been shown that the spiracles of insects are generally closed, and are opened only when air is required (Wigglesworth, 1934). It may be that the mosquitoes closed their spiracles, and that by thus 'holding their breath' avoided the effects of change of pressure. But in any case, the survival of the mosquitoes sent by us to Amsterdam shows that *Aedes aegypti* can withstand the changes of altitude which are usual in the commercial aeroplane of the present day.

4. DESTRUCTION OF MOSQUITOES IN AEROPLANES.

No method of de-insectisation is effective unless it is properly applied. It must be in the hands of men who are trained in its use and are responsible for the results. Therefore it cannot be relied upon if carried out during flight by the crews of aeroplanes, who are not trained to the work and have other duties

to occupy them. If, however, de-insectisation is undertaken when the aeroplane is on the ground, before departure or after arrival, it can be done by the responsible Public Health organisation.

Any method applied to aeroplanes must be rapid in order to avoid delaying traffic. It must of course also be effective, and harmless to human beings and fabrics.

Hydrocyanic acid gas, carboxide and pyrethrum extracts have been used for the destruction of mosquitoes. Hydrocyanic acid gas is unsuitable for aeroplanes in transit, as the least carelessness may cause a disaster, and some time is required for ventilating the machine after use. Carboxide is less efficient, is irritating to the lungs and requires a longer exposure (Michel, 1935; Williams and Dreessen, 1935). Pyrethrum has been shown to be rapid, efficient and safe (Gnadinger, 1933; Sinton and Wats, 1935; Michel, 1935; Williams and Dreessen, 1935, 1935*a*). There are many proprietary preparations on the market, of which some are efficient and some are useless (Swellengrebel and Nykamp, 1934; Sinton and Wats, 1935; Baber, 1934). There are also on sale concentrated liquid extracts of pyrethrum from which insecticidal solutions can be prepared, which are as efficient as the best commercial fluids and are much cheaper. Sinton and Wats used the Pyrocide 20 solution of the McLaughlin Gormley King Co. Baber obtained the best results from the extract of Messrs. Stafford Allen, Ltd., and good results with Pyrocide 20 and the extract of Messrs. Gale and Co., Ltd. Williams and Dreessen (1935*a*) have recently shown that a kerosene extract of pyrethrum may advantageously be mixed with carbon tetrachloride, to give an efficient and non-inflammable spray. In the following experiments we examined the practical application of Pyrocide 20 solutions to aeroplanes on the ground.

Two spray 'guns' of the usual commercial type proved unsatisfactory. The amount of liquid delivered by each stroke of the pump was not constant, so that it was difficult to spray a known volume. The spray thrown by them was not homogeneous; it contained many large drops which fell to the ground without exerting any toxic action; and it was thrown only a short distance. After this, in all our experiments, we employed a paint sprayer, which was lent by the Karachi Aero Club. This used compressed air, with an initial pressure of 60 lbs., falling to a point between 15 and 30 lbs. The spray was fine, homogeneous and penetrating and in every way better than that thrown by the spray guns*.

To standardise the conditions as far as possible, we used only female *Aedes aegypti*, from one to three days old, bred in the laboratory and fed on raisins. They were enclosed in small circular cages, three inches in diameter and one inch thick, which were covered with cotton mosquito-netting having a mesh of 41/42.

Under natural conditions mosquitoes conceal themselves behind curtains, among clothes and in other places where they are protected and are not easily seen. Since the object of our experiments was to examine the *practical* application of the insecticide, which includes its rapid penetration to concealed insects, the cages were usually placed in positions which gave some protection to the contained mosquitoes.

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* The portable 'Whippet' Aerograph outfit sold by Messrs Gillanders, Arbuthnot and Co., Ltd., appears suitable for the work. The complete outfit with an electric motor costs Rs. 310.

Because the de-insectisation of an aeroplane after landing must be rapid, a five minutes' exposure was taken as the standard. Preliminary experiments (Table IV) were made to determine the dose of Pyrocide 20 which would kill *Aedes aegypti* in this time, even when the mosquitoes were partly protected by furniture. In a small room of 1,170 cubic feet all apertures were blocked. Six cages, each holding ten mosquitoes, were disposed about the room so that some cages were fully exposed to the spray, while others were partly protected by furniture. The cages were wrapped in paper, which was removed when the measured volume of Pyrocide dilution had been sprayed. After five minutes' exposure the cages were removed to another room, and examined after intervals of five minutes, thirty minutes, and on the next day. The mortality was recorded as the number which, on the next day, were unable to fly. Those which could move their limbs without being able to fly were included among the dead.

Throughout these experiments, the dose of Pyrocide is recorded as so many cubic centimetres of the undiluted extract to 1,000 c.ft., although the space actually sprayed varied from 600 to 1,170 c.ft. The Pyrocide 20 solution was mixed with kerosene before use; the dilution was 1 in 20, except where otherwise stated. The kerosene was 'Elephant' brand. 'Horse' and 'Rising Sun' brands are also suitable (Sinton and Wats, 1935).

TABLE IV.

Toxicity of Pyrocide 20 *to* Ædes ægypti *in a small room. The dose is shown in c.c. of undiluted pyrocide to* 1,000 *c.ft. of space. Before use it was diluted to* 1 *in* 20 *with kerosene. Exposure, five minutes.*

Number.	Dose in c.c.	Percentage dead.	Controls.		Temperature (°Fahrenheit)	Relative humidity, per cent.
			Number.	Number dead.		
1	0·5	59 *	25	1	90·5	62
2	1·0	96	25	1	86·5	68
3	1·5	100	25	2	87·5	70
4	1·5	96	25	0	84·5	69
5	1·5	96	25	0	82·0	73
6	1·5	100		..	86·0	62

* One mosquito lost; fate unknown.

As a result of these tests we used for the most part a dose of 1·5 c.c. of Pyrocide 20 per 1,000 c.ft., in aeroplane experiments.

Table V summarises the experiments in the rear cabins of the 'Hannibal' class. This cabin is between 700 and 800 c.ft., and has about fourteen seats. In some machines the sides of the seats are carried down to within three inches of the floor, surrounding a space which is open below, and affords an ideal hiding place for mosquitoes. The aeroplane in Experiment 1, however, had no such spaces.

TABLE V.

Toxicity to Ædes ægypti *of Pyrocide* 20, *when sprayed in the cabins of 'Hannibal' class aeroplanes. The dose is shown in c.c. of undiluted Pyrocide to* 1,000 *c.ft. of space. Before use it was diluted to* 1 *in* 20 *with kerosene. Exposure, five minutes.*

Number.	Dose in c.c.	Percentage dead.	Controls.		Temperature (°Fahrenheit).	Relative humidity, per cent.
			Number.	Number dead.		
1	1·0	100	25	2	87·0	70
2	1·5	60	25	0	88·0	60
3	1·5	82	25	0	83·5	73
4	1·5	88	25	5	96·0	36
5	2·0	93	25	1	81·0	45
6	3·0	100	25	1	80·0	45

In no. 1, two cages were on the luggage rack, two behind window curtains and two beneath the seats. The spray was directed to all parts of the cabin, so as to fill it with a fine mist, but was never pointed behind the curtains or under the seats. The penetration of the spray was sufficient to give a lethal dose to all mosquitoes in five minutes.

In nos. 2 to 6, two cages were placed behind window curtains and four in the box-like space under the seats.

In no. 2, the mixture was sprayed generally throughout the cabin, but not directly under the seats or behind the curtains. Many mosquitoes survived.

In nos. 3 to 6, part of the spray was thrown directly into the space beneath the seats. More mosquitoes were killed, but not until a dose of 3·0 c.c. was used were all destroyed. These spaces obviously afford excellent protection to mosquitoes, and should be closed. Other hiding places in the cabin were less secure. They were penetrated by a spray diffused generally throughout the cabin, so that it was unnecessary to point the nozzle into each possible hiding place.

It is probable that the cages gave some protection to the mosquitoes. Any error thus introduced in estimating the lethal dose is on the side of safety.

There are other spaces into which it is difficult for the operator to penetrate. The rear end of the fuselage, behind the cabin, is obstructed by cross-bracing wires and has often no safe foothold. In the 'Atalanta' class of monoplanes, the interior of the wing communicates with the cabin. The opening is closed by a panel, but this is often removed when the machine is being overhauled, and there is then nothing to prevent the entrance of mosquitoes. It is not practicable for a man to carry a spray into these spaces, if the work is to be done quickly. We therefore examined the penetration of a spray thrown

into the rear end by an operator standing in the cabin. In each of these experiments, six cages, each holding ten mosquitoes, were used for the test, and twenty-five mosquitoes were held as controls. The results are shown in Table VI.

TABLE VI.

Penetration of a spray directed down the rear end of the fuselage. The spray was Pyrocide 20, diluted 1 in 20 with kerosene. Doses in c.c. to 1,000 c.ft.

No.	Class of aeroplanes.	Dose in c.c	Percentage dead.	Controls.		Temperature (°Fahrenheit).	Relative humidity, per cent.	Exposure, minutes.
				Number.	Number dead.			
1	'Atalanta'	1·5	97	25	0	87	68	5
2	"	1·5	100	25	4	91	62	5
3	'Hannibal'	1·5	55	25	0	87	60	5
4	"	1·5	98	25	2	..	..	5
5	"	1·5	45 *	25	1	95	37	5
6	"	1·5	40	25	0	..	..	5
7	"	3·0	88	25	3	98	30	5
8	"	3·0	100	25	0	82	42	15
9	"	1·5	95	25	1	94·5	35	15

* Two mosquitoes lost; fate unknown.

In the 'Atalanta' class (nos. 1 and 2), apertures in the fuselage were blocked and cages were hung from the cross-bracing wires at distances of ten to twenty-five feet from the door between the rear end and the cabin. The mixture was sprayed into the rear end by a man standing in the doorway. After five minutes' exposure, the cages were wrapped in paper and removed from the aeroplane. Nearly all the mosquitoes were killed.

In the 'Hannibal' class (nos. 3 to 9), the apertures in the fuselage were also blocked. Near the extremity of these machines there is an inspection panel. Cages were introduced through this, so that they were from twenty-four to thirty feet distant from the door, through which the mixture was sprayed.

The killing effect of the spray was not satisfactory until the time of exposure was raised to fifteen minutes. We attribute its failure to the distance between the mosquitoes and the spray, and to difficulty in closing the apertures in the extremity of the fuselage, which are more numerous in these machines than in the 'Atalanta' class. When the spray must be thrown a long distance, a slight leakage will prolong to more than five minutes the time required to reach a killing concentration. Even when the dose of Pyrocide was increased to 3·0 c.c., only 88 per cent of mosquitoes were killed in five minutes. But when the time of exposure was raised to fifteen minutes, all were killed by a dose of 3·0 c.c.,

and 95 per cent by a dose of 1·5 c.c. We therefore conclude that, when the spray must be thrown a long distance, all holes must be carefully blocked and the time of exposure must be at least fifteen minutes. It will not delay traffic as these spaces need not be entered during the business of unloading.

Summarising the above, we find that in these experiments an efficient spray was given by a dose of 3 0 c.c. of Pyrocide 20, diluted to 1 in 20 with kerosene, for each 1,000 c.ft. of space. For cabins and baggage rooms an exposure of five minutes was enough. In less accessible spaces, the same dose killed at a distance of thirty feet, when apertures were blocked and the time of exposure was fifteen minutes. This concentration was only mildly irritating to the eyes and nose. If it is found to have a cumulative effect, the operator can wear a mask. The cost of the mixture required for an aeroplane of the 'Hannibal' class is one and a half annas at present prices.

THE RELATIONSHIP OF METEOROLOGICAL FACTORS AND DILUTION OF INSECTICIDE TO THE TOXIC PROPERTIES OF PYROCIDE 20.

The mortality among mosquitoes rose as the dose of Pyrocide was increased. Since the dilution of Pyrocide was always 1 in 20, an increased dose of Pyrocide involved an increased volume of the diluted mixture, and so a larger number of droplets was sprayed. According to Gnadinger (1933), pyrethrum extracts kill by contact. The larger the number of droplets, the greater is the chance of contact, especially when the time of exposure is short and the mosquitoes are free to conceal themselves. How much was the effect of the larger dose due to an increased volume of fluid ? We were able to make only a few experiments in search of an answer to this question.

Mosquitoes and cages were prepared as in the previous experiments. Five cages, each holding twenty mosquitoes, were pinned under a bench, so as to be protected from the direct action of the spray. The room was that previously used, of 1,170 c.ft. capacity. The mixture was sprayed into the upper part of the room, but never directly on the mosquitoes under the bench. Five minutes after spraying was finished, the cages were wrapped in dusters while still in position and then removed to another room for examination. The mortality is recorded as the percentage unable to fly on the following day.

In the first series (Table VII, Fig. 1), the volume of diluted fluid was kept constant at 20 c.c. to 1,000 c.ft., while the dose of Pyrocide was varied.

The results recorded in Table VII and Fig. 1 show that the mortality rose with an increase in the dose of Pyrocide. The correlation between the two variates is significant, when tested by the method of Fisher (1934). The graph drawn to a logarithmic scale indicates that the rate of increase of mortality was regular throughout the range of the experiments. The effect of variation in relative humidity is not apparent.

For the converse experiments the dose of Pyrocide 20 was held at 0 5 c.c., while the total volume was variable. During these experiments there was a change of weather. The wind began to blow from the north, as is usual in Karachi in October, and there were considerable variations in humidity, which seem to have influenced the results (*see* Table VIII, Fig. 2).

TABLE VII.

Action of Pyrocide 20 on Ædes ægypti. *Total volume of mixture constant; dose of Pyrocide variable. Dose in c.c. to 1,000 c.ft. Exposure, five minutes.*

No.	Total volume in c.c.	Dose of pyrocide in c.c.	Percentage dead.	Controls. Number.	Controls. Number dead.	* Corrected mortality.	Temperature (°Fahrenheit).	Relative humidity, per cent.
1	20	0·0	1	50	1	0·0	83·5	42
2	20	0·25	9	50	0	9·0	85·5	64
3	20	0·5	20	39	2	15·7	84·5	52
4	20	1·0	37	35	2	33·2	86·0	56
5	20	1·0	33	25	0	33·0	87·0	63
6	20	1·5	88	50	2	87·5	86·0	62

Coefficients of correlation;
dose of Pyrocide and corrected mortality, 0·93; $t = 5{\cdot}21$; P less than 0·01; significant.
humidity „ „ 0·51; $t = 1{\cdot}19$; P 0·3; not significant.

* The correction was calculated by assuming that, in the absence of Pyrocide, there would have been the same natural mortality among the test mosquitoes as was observed among the controls, but that, since Pyrocide was used, there must be credited to it a proportion of deaths among those which would later have died naturally. The proportion was calculated by the formula $c = \frac{de}{100-e}$, where

$c =$ deduction from percentage mortality to give corrected mortality,
$d =$ number of survivors observed in test,
$e =$ percentage mortality among controls.

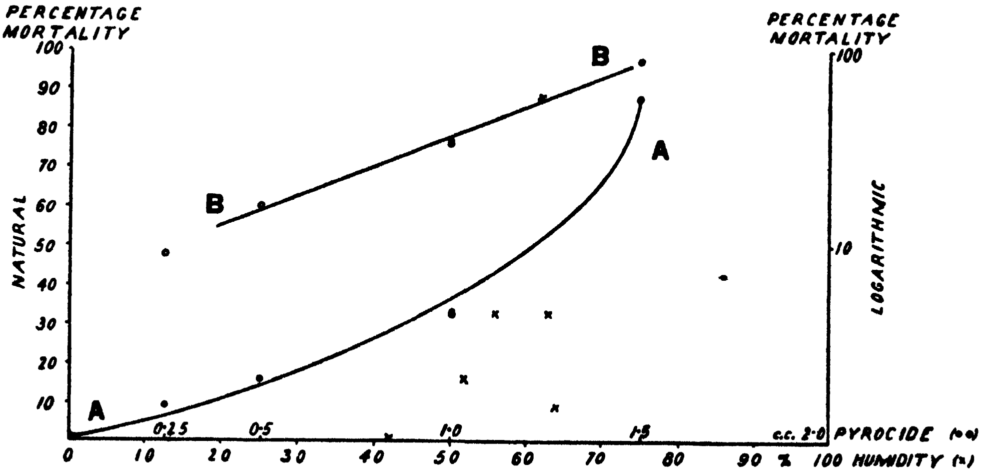


Fig. 1. *Action of Pyrocide 20 on* Ædes ægypti. *Total volume of mixture constant; dose of Pyrocide variable. Dose in c.c. to 1,000 c.ft. Exposure, five minutes. The corrected mortality is plotted against the dose of Pyrocide; A—A, natural scale; B—B, logarithmic scale. The corrected mortality is also plotted on the natural scale against the relative humidity (crosses).*

TABLE VIII.

Action of Pyrocide 20 on Ædes ægypti. Dose of Pyrocide, 0·5 c.c., volume of mixture variable. Total volume of mixture in c.c. to 1,000 c.ft. Exposure, five minutes.

No.	Total volume in c.c.	Dose of pyrocide in c.c.	Percentage dead.	CONTROLS. Number.	CONTROLS. Number dead	* Corrected mortality.	Temperature (°Fahrenheit).	Relative humidity, per cent.
1	10	0·5	35	50	0	35·0	85·0	50
2	20	0·5	27	50	1	25·5	84·0	53
3	20	0·5	70	50	8	64·3	84·5	41
4	40	0·5	95	30	1	94·8	87·0	35

Coefficients of correlation;
volume of mixture and corrected mortality, 0·84; $t =$ 2·22; P 0·1 to 0·2; not significant.
humidity „ „ „ —0·99; $t = -12·78$; P less than 0·01; significant.

* For explanation of correction, *see* below Table VII.

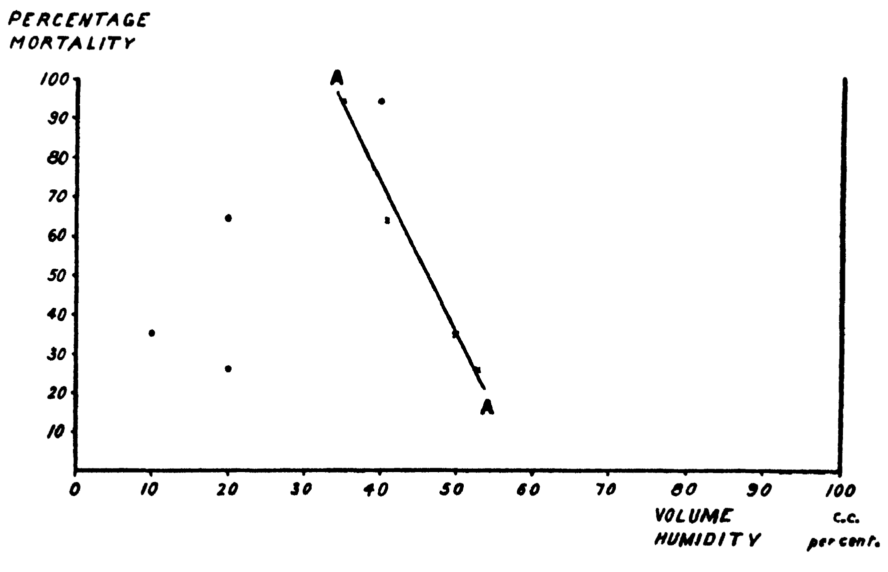


Fig. 2. *Action of Pyrocide* 20 *on* Ædes ægypti. *Dose of Pyrocide,* 0·5 *c.c., volume of kerosene variable. Relation of corrected mortality to changes in the total volume of mixture* (*dots*), *and to variation in relative humidity* (*crosses, A — A*).

Four experiments are hardly enough to justify definite conclusions. Moreover, the heavy mortality among the controls in Experiment 3 greatly reduces its value. However, the variation in mortality seems to be correlated with changes in humidity rather than with variation in the total volume of mixture. When the air became drier, the spray was more effective. A similar variation

with humidity is seen in the experiments of Sinton and Wats (1935). The range of temperature in our experiments was too small to produce any obvious effect.

There is no doubt an optimum dilution of Pyrocide 20. But these few experiments suggest that changes in dilution are of little importance compared with changes in the dose of pyrocide employed.

5. MOSQUITO-PROOFING OF AEROPLANES.

The different types of aeroplane vary so much that detailed design of mosquito-proofing devices is impossible. Only general principles can be suggested.

Windows in most modern aeroplanes are not made to open. Air is led into the cabin by ducts, which are controlled by the passengers.

Doors should fit closely. Double mosquito-proof doors, of the kind provided in houses, are not practicable for want of space.

The spaces under the seats of some Imperial Airway liners of the 'Hannibal' class may be closed with sheet metal or three-ply wood. Mosquito-netting is unsuitable for this purpose.

Ventilators may be covered with mosquito-proof wire gauze screens.

In the wings and fuselage there is usually a number of apertures. Some are for control wires, for the shock absorber or for other moving parts. They may be closed by a loosely-fitting sleeve of fabric which is continuous with the fabric of the body. Other openings are intended to allow mechanics to grease or adjust the interior structures. They may be closed by a spring flap, a sliding shutter, or flaps of fabric which are held together by Zip fasteners.

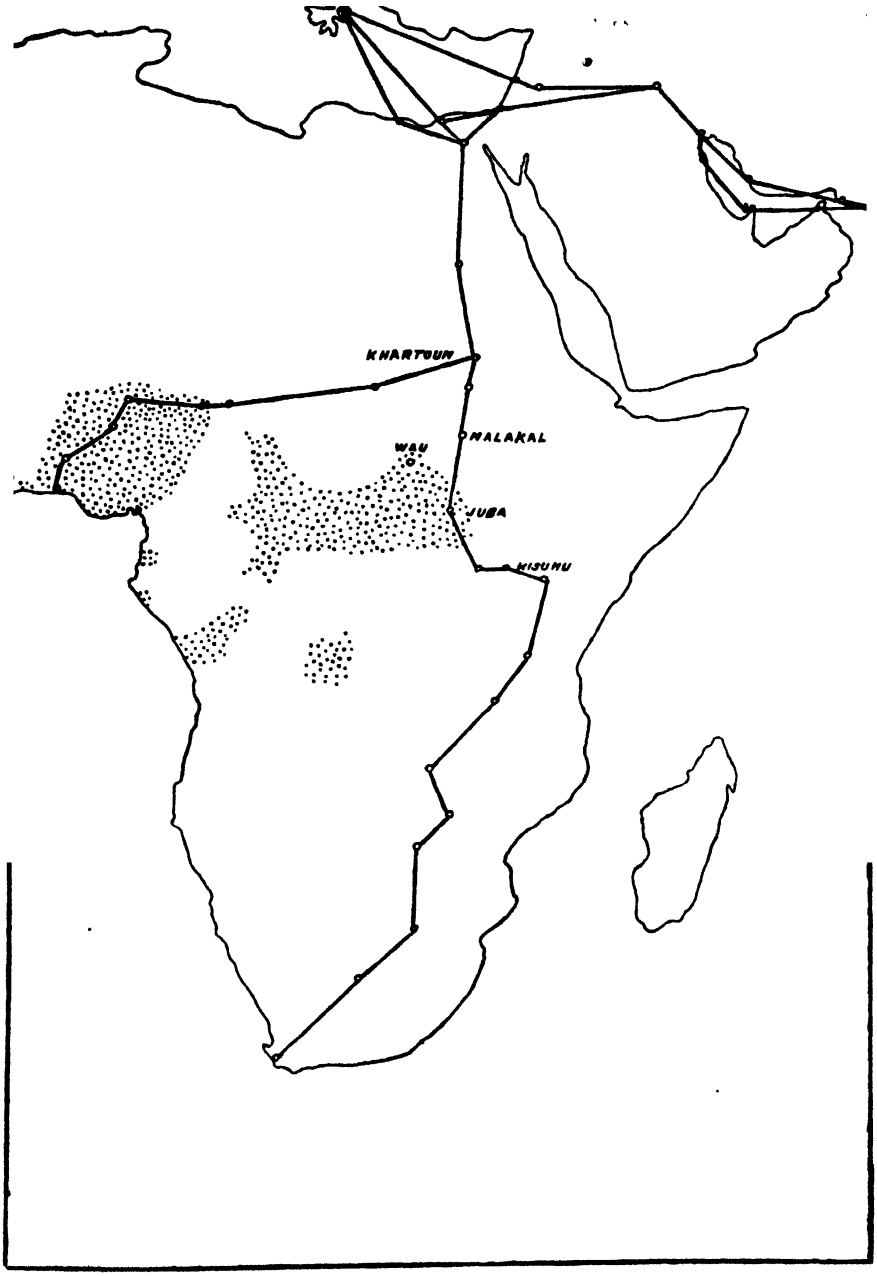
When a machine lands, which is suspected of carrying dangerous mosquitoes, it is desirable to allow the passengers, but not the mosquitoes to emerge. This may be done by applying a mosquito-proof cage to the door of the aeroplane. Such a structure would be a wooden or metal frame, mounted on wheels and covered with mosquito-proof wire gauze screening. The outer end would be closed by a spring door, while the inner end would fit closely against the side of the aeroplane, and be large enough to allow the door of the aeroplane to open inside it. A cage of this type has been used in Kenya Colony (Symes, 1935).

An aeroplane so proofed should retain mosquitoes within it until they can be destroyed by an insecticide. On the other hand, the various apertures must be opened at times to allow mechanics to grease and overhaul the internal structures. Mosquitoes which enter at these times will be retained in the machine and carried to the next stopping place, perhaps biting passengers on the way. A decision as to the desirability of mosquito-proofing aeroplanes depends on the opinion formed of the balance of advantages and disadvantages.

6. DISTRIBUTION OF YELLOW FEVER.

The distribution of yellow fever, according to the information now available, is shown in the accompanying map. It is based on the reports of clinical cases and protection tests published by Beeuwkes, Bauer and Mahaffy (1930), Beeuwkes, Mahaffy, Burke and Paul (1934), James (1934), Hewer (1934) and Boyé (1935). Areas giving not more than one positive protection test have not been included in the yellow fever area, as a single positive is within the limits

MAP.



Distribution of yellow fever and routes of air services to India and East Africa, with the projected service from Khartoum to Lagos. Yellow fever areas are shaded.

of experimental error. Other areas in which positive results were given only by non-residents, *e.g.*, Khartoum, are also excluded.

No evidence of immunity to yellow fever was found in Morocco, Egypt, Kenya, Tanganyika, Abyssinia, Zanzibar, Southern Rhodesia, Bechuanaland or the Union of South Africa. In these countries 856 sera gave 0·8 per cent positive protection tests (Sawyer, 1934).

7. DISCUSSION.

What is the probability that aeroplanes may carry infected *Aedes aegypti* into India ?

Infected regions which are traversed by air lines are the Sudan now, and in the future Nigeria. In the Sudan yellow fever has been recognised by biological methods and there was a single case at Wau, but there has been no frank epidemic, and no European is known to have suffered. It has been shown in Section 1 of this paper that when *Aedes aegypti* is placed in aeroplanes, it can make a journey as long, in distance and time, as that from the Sudan and Nigeria to India. But the evidence collected in Section 2 shows that in nature it very rarely undertakes such journeys, so that in fact the danger that the insect may be imported from the Sudan to India is small. Since Juba and Malakal are anti-amaryl aerodromes, the risk of importation of an *Aedes aegypti* is much diminished; and the chance of such a mosquito being an infected female is correspondingly smaller. This view agrees with that expressed by the Cape Town Conference of November 1932 (League of Nations, 1933), which reported that ' Experiments demonstrating that ædes mosquitoes can travel long distances by aeroplanes were cited, but it was agreed that the risk of transporting mosquitoes in an infective condition is comparatively small and can be met by the simple measure of de-insectisation of aeroplanes '.

If an epidemic were to appear in northern Egypt, the position would be altered. But in this case air traffic from Egypt to India would probably be suspended, in order to prevent infection from being carried by man.

The danger from Nigeria is rather greater, because no anti-amaryl aerodromes are known to have been established and because clinical cases have been recognised. In 1934 there were five European cases of yellow fever at Kano (Boyé, 1935). At the present time it is unlikely that an aeroplane would fly through from Nigeria to India, but in any case it may be considered desirable to prohibit it.

SUMMARY.

1. Female *Aedes aegypti*, despatched from Karachi in aeroplanes, travelled alive to Amsterdam and over a considerable part of the return journey. A summary is given of the published reports of similar experiments in America and the Belgian Congo.

2. One hundred and six air liners arriving at Karachi were searched, but no mosquitoes were caught. A summary is given of the published reports of similar searches in other countries.

3. *Aedes aegypti* seemed to suffer no ill-effects when exposed to reduced atmospheric pressure.

4. Experiments on the destruction of *Aedes aegypti* in aeroplanes indicated that they were destroyed by a spray of Pyrocide 20 in amounts equivalent to 3 c.c. per 1,000 c.ft., with an exposure of five minutes for cabins and baggage rooms, and of fifteen minutes for less accessible spaces. Before use, this dose was diluted to 1 in 20 with kerosene.

5. The results of a small number of experiments suggested that the killing effect of the mixture varied with the dose of Pyrocide, and that the degree of dilution was of minor importance. The influence of changes in humidity was also demonstrated.

6. Methods of mosquito-proofing aeroplanes are suggested.

7. A map shows the known distribution of yellow fever in the regions of Africa traversed by air liners.

8. Conclusion. There is at present little danger of the import of infected *Aedes aegypti* from the Sudan to India. The danger from Nigeria is rather greater.

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Records of the Malaria Survey of India, 6, 1, March, 1936.

WHAT MALARIA COSTS INDIA, NATIONALLY, SOCIALLY AND ECONOMICALLY—(*Concld.*).

BY

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* Published in *Records of the Malaria Survey of India* (1935), 5, 3, pp. 223–264.
† Published in *Records of the Malaria Survey of India* (1935), 5, 4, pp. 413–489.

F. ARE ANTI-MALARIAL OPERATIONS PAYING PROPOSITIONS?

'All malaria control, and indeed, sanitation in general, is a source of expense. But it is not yet always clearly apprehended that malaria, like other diseases, is also a source of expense—and usually of much greater expense than preventive measures are likely to be. It is useful to consider this subject from a strictly business point of view, quite apart from humanitarian interests. Every case of malaria, both among staffs and among labourers, costs money; and sometimes large sums of money have to be wasted under this heading' (Ross, 1926).

'Parkes says "it has been proved, over and over again, that nothing is so costly in all ways as disease, and that nothing is so remunerative as the outlay that augments health, and in doing so augments the amount and value of the work done"' (Mackenzie, 1929*b*).

'Nothing costs the individual ratepayer more than sickness and mortality' (Nankivel, quoted by Balfour, 1928).

'It (malaria) is now becoming thoroughly understood in these States not only as an evil that can be abated and ultimately exterminated, but also as an economic incubus that must be repudiated' (Leathers, 1918).

'As it (malaria) is a preventable disease, its continued prevalence is a reproach to the people, and its eradication would be a good money investment' (University of Missouri Bulletin, 1916).

'There is a considerable mass of evidence to show that, in the past twenty years, sanitary work generally, and particularly the control of malaria in conjunction with other measures, has saved 100,000 lives in the Malay Peninsula, and an enormous, but incalculable, amount of money' (Watson, 1921).

'Nevertheless, it may with confidence be said that the eradication of malaria in India would, in a single generation, convert that country into one of the most prosperous in the world' (Hehir, 1927).

'It is true, of course, that malaria in India is absolutely of the very first order of practical importance, and that any measures and means of the Government in the direction of malaria prevention are certain to prove productive of enormous value to the people of India' (Hoffman, 1928).

The dire effects which malarial prevalence has upon the population of India and other malarious countries, through its action in increasing the death rate, the morbidity, and the suffering of the inhabitants, have been clearly shown in the previous sections of this paper. It is evident, therefore, that, from the standpoint of the humanitarian alone, it is the duty of every Government, every administration and every public body to use all means in their power to prevent or ameliorate the ravages of this disease.

That successful operations against malaria have a beneficial effect upon the natural increase of the population, upon their health, vitality and physical development and upon their social, intellectual and political progress, has been recognised and proven in many parts of the world where such measures have been taken. The increased prosperity which follows naturally on such benefits, is a paying proposition for any community, country or nation.

It is usually impossible to evaluate in rupees, annas, and pies, the direct and indirect benefits, whether economic, sanitary, or social, which anti-malarial operations confer upon a previously malaria-stricken population. It is unfortunately the direct financial results upon which these benefits are too often evaluated.

The enormous financial losses which malaria causes to the people of India have been discussed in detail already. In view of the immensity of these, it would certainly pay India to spend very much larger sums than she does at present in efforts to counteract them.

The detrimental influence of malaria upon the various aspects of the labour problem, through its effects in retarding the development of her natural resources to their full degree, is one of the chief causes of financial wastage. Numerous large undertakings in the tropics now recognise the importance of this disease as an economic factor. Many of these have already found that it is a paying proposition to finance active measures to reduce the harmful effects that this disease produces among their employees. As remarked by Le Prince (1919), malaria eradication is a work that advances trade and prosperity wherever seriously undertaken.

The ideal to be aimed at in all anti-malarial campaigns is the eradication of the disease, but unfortunately, in our present state of knowledge, this is not financially possible in all instances. Up to the present, the most successful attempts at eradication have depended upon the destruction of the insect vector of the disease, but, in the majority of instances, the expenditure needed for such measures can only be found where a large number of settled inhabitants are congregated together, as in cities and towns, or where it is necessary to protect a more limited population, whose health is particularly valuable and is especially threatened.

As malaria is pre-eminently a rural disease, and the afflicted are proverbially poor, in very large areas neither the inhabitants nor the local authorities are in a position to pay for such a relatively expensive measure of eradication as mosquito destruction. In such circumstances all that can be hoped for, in our present state of knowledge, is to use those measures which will hold the disease in check and ameliorate its ravages on the health of the community. When the beneficial effects of such measures are felt, the population will then be in a better position, economically, physically, intellectually, and socially, to initiate a more active campaign aimed at the eradication of the disease.

It is, of course, impossible to review all the examples which have been recorded of the benefits conferred by operations against malaria. A few of these are given below to illustrate various circumstances and conditions in which they have proved of value.

In recording these examples it is convenient to consider the reported benefits in two main divisions, namely (1) those obtained in special settled collections of people, and (2) those in scattered populations and temporary aggregations of people. The former have been due chiefly to measures having mosquito eradication as their object, while the latter have been obtained mainly by measures aimed at the amelioration of the effects of the disease. In many instances, of course, a combination of several of the recognised methods of malaria prevention has been employed.

(I) RECORDED BENEFITS OF ANTI-MALARIAL MEASURES IN SPECIAL SETTLED COLLECTIONS OF PEOPLE.

The reports of the benefits of such control may be discussed most easily under the following headings :—

(*a*) Malaria control in urban areas; and

(*b*) Malaria control among special stable aggregations of people.

(*a*) THE BENEFITS OF MALARIA CONTROL IN URBAN AREAS.

The habitat of most dangerous Anophelines is usually rural, and with the installation of various measures of sanitation and drainage, which are the

concomitant features of urban life, the facilities for the breeding of these insects are usually markedly diminished. Urbanisation of malarious areas has commonly a great effect in diminishing the incidence of the disease.

In urban areas the anti-malarial measures which are most likely to be profitable, and most economical in the long run, are those which aim at a more or less permanent eradication of the dangerous mosquito. Although the provision of treatment will be necessary, especially in the early stages of such campaigns, the need for this will diminish as the mosquito danger is eliminated, or controlled, by abolition of breeding places, by screening, etc. Measures for mosquito eradication are usually only financially possible in such densely populated localities, because the large number of persons gathered within a relatively small area, make available a larger sum of money to deal with the area, and so a greater number of persons can be protected by a sum which would be inadequate for a more widely scattered population living in similar malarious environments.

It has been in connection with such large collections of people that many of the most successful results of anti-malarial work have been reported.

In the City of Panama the death rate per 100,000 from malaria in the quinquennium 1901–1905, before anti-malarial measures were started, was 973·5 as compared with 159 9 during the period 1911–1915 (Hoffman, 1928)*. In Havana City, as the result of an anti-mosquito campaign directed mainly against yellow fever, the malaria death rate fell from 151 in 1901 to 32 in 1905 (Watson, 1935).

The Annual Report of the Rockefeller Foundation for 1925 tells us that in 1920, 1921, and 1922, the Board of that Foundation and the United States Public Health Service aided a number of towns in the United States in demonstrating the economic feasibility of complete mosquito control. These demonstrations were so successful that the work has been continued by the States and towns themselves, and is extending to all parts of the South. Rose (1919) has discussed in detail the results obtained by these anti-malarial measures (drainage and oiling). Some of the benefits reported from 6 towns in the State of Arkansas are summarised in Table VI, which also shows the cost of the work.

It is stated by Taylor (1920) that in these towns the ague rate was reduced about 73 per cent at a cost of $0 84 per head, and the Rockefeller Foundation in its Annual Report for 1919 records that the result of this work shows that it costs the community approximately a fourfold greater sum to harbour malaria than to banish it. As remarked by Hoffman (1928), 'the results admirably illustrate the efficiency of active co-operation on the part of the International Health Board, the United States Public Health Service, the local authorities and the large employers of labour'.

These results were so successful that it was decided to extend them to other communities.

Ferrell (1920) states that control operations during 1920 would extend to 60 or 70 counties in the southern United States, at a cost of nearly half a million dollars. In the

*'Statements to the effect that malaria has been eradicated from the Canal Zone are erroneous'...... 'Our anti-malarial efforts being confined to the more important towns and their environs'. Despite the great decrease in malarial incidence and the practical elimination of deaths, this disease still continues the greatest single cause of admission among employees, 'These are figures of interest as showing what an all-important factor malaria is in any tropical country' (Chamberlain, 1929).

TABLE VI.

Results of anti-mosquito measures in 6 towns in Arkansas, in U. S. A.

	Names of towns.					
	Crossett.	Hamburg.	Lake Village.	Dermott.	Monticello.	Bauxite.
Population.	2,029	1,285	975	2,760	3,023	2,500
Physicians' calls for malaria.—						
1915 ..	2,500	?	?	?	?	?
1916 ..	741	2,312	1,817	1,399	1,413	862
1917 ..	200	259	1,388	1,248	1,274	729
1918 ..	73	59	83	162	137	172
Percentage reduction.	97·1 (in 3 yrs)	97·4 (in 2 yrs.)	94·8 (in 1 yr.)	87·8 (in 1 yr)	89·8 (in 1 yr.)	78·4 (in 1 yr)
Per capita cost.—	*	*				
1916 ..	$1.24	..	..	..	..	..
1917 ..	$0.63	$1 45	..	..	..	..
1918 ..	$0.53	$0 44	$1.25	$0.54	$0.46	$1 11

* Omitting overhead costs

five years' previous work the *per capita* cost had varied from a quarter of a dollar to nearly a dollar and a half, while the consequent reduction in malaria was estimated at 72 to 97 per cent.

The profitable nature of anti-malarial measures in several other towns has also been emphasised by Fuchs (1922).

'In nearly 100 communities undertaking malaria-control work in the last few years, the average cost for the first year was about 80 cents per person, or a little over $1 per acre. The annual cost of maintaining the work in these towns after the first year averaged 20 cents per person, or 35 cents per acre'...... 'As a result of these modest expenditures, the incidence of malaria has been reduced 75 to 95 per cent in these communities. Insurance claims paid for reasons of disability from malaria among mill hands at the Pittsburg Plate Glass Co, Crystal City, Mo., dropped from $230 in 1915 to $61 in 1916, following control work. That money spent for anti-malarial work is an investment, not an expenditure, and a profitable investment at that, is shown in the following tabulation (Table VII). Profits from 73 per cent up to over 1,000 per cent are reported' (Fuchs, 1922).

From a study of the results of this work, Rose (1919) concludes that 'for the average town in our Southern States having a thousand or more inhabitants and a reasonably high infection rate, malaria control by anti-mosquito measures is economically feasible; it is, in fact, a sound business proposition'.

The beneficial effects of these measures were indicated by their direct result upon the health of the communities protected, and upon the various aspects of the labour problem. They were greatly appreciated not only by officials, but also by numerous commercial, industrial and other business concerns located in these towns.

TABLE VII.

Profits on investment in malaria control.

Place.	Year.	SAVING DUE TO CONTROL.			
		Cases prevented.	Losses prevented (dollars).	Cost of control work (dollars).	Profit on investment (per cent).
Brownsville, Tenn. ..	1920	81	3,193	1,848	73
Cairo, Ga.	1920	54	2,523	856	195
Chester, S. C. ..	1920	356	24,700	8,719	183
Cotton Belt Railway ..	1917–1920	1,403	140,300	42,000	233
Demopolis, Ala. ..	1920	182	25,724	3,000	757
Goldsboro, N. C. ..	1920	810	20,250	10,052	102
Mitchell County, Ga. ..	1919	..	40,570	3,580	1,030
Thomasville, Ga. ..	1920	182	25,724	3,000	757

'In certain instances where the town officials were under the impression that the expense of a mosquito drainage campaign would be beyond their financial ability, they were astounded to discover that the annual cost of screening houses and screen repairs greatly exceeded the cost of mosquito elimination' (Le Prince, 1919).

The Mayor of Union City, Texas, states—'There could not have been a better campaign for any purpose than this one, and the money spent was the best investment we have made during my regime. We want to urge our successors to keep this good work going' (Fuchs, 1922).

'Industries in infested areas report from 10 to 40 per cent increased output after control measures were in operation. Chambers of commerce report new industries establishing branches in towns where the elimination of malaria rendered local labor more efficient, and factory managers report that, since malaria-control measures were carried out, there is a more steady supply of labor, that the quality of the labor has improved and the earning capacity of the laborer increased' (Hardenburg, 1922).

After 2 years' experience of anti-mosquito measures, the treasurer of the Roanoke Cotton Mills Co. says, 'The money spent in anti-malaria work here has paid the quickest and most enormous dividends I have ever seen from any investment, and after having had our experience I would, if necessary, do the work over again if I knew it would cost 10 times the amount'...... 'Our experience has taught us that the eradication of mosquitoes is not only the proper thing to do from a strictly health standpoint, but it is an exceedingly profitable thing to do' (Fuchs, 1922).

A doctor in Humboldt writes—'In view of my reduced practice, the $15 I contributed to the anti-malaria campaign was the worst investment I ever made' (Fuchs, 1922).

'At Anderson malaria has been reduced to a negligible factor and, as a result, it has been estimated that more real estate has changed hands in the last year than has previously been sold in ten years, new people and new capital are being added to the district and the general impression of the town is of a healthy, prosperous community, quite unlike the Anderson of two or three years ago' (Rept. of Coll. Agric. and Agric Exp. Station of Univ., California, 1920-1921).

Cities and towns in many other countries, that have undertaken systematic anti-malarial campaigns, have benefited not only through their improved health conditions but also financially.

The magnificent work of Missiroli and Hackett in Italy and Sardinia, by mosquito control in connection with cities and small towns, shows how great the success is which can be obtained when one has a combination of 'the intelligence, enthusiasm, and energy of those responsible for sanitary affairs'. In

Southern Italy, the most malarious portion of that country, about 88 per cent of the population are collected into towns, thus making local anti-larval measures a much more feasible, and economically practicable, proposition than it would be in countries like India, where 90 per cent of the population is widely scattered in rural areas. Under the former conditions, the Rockefeller Foundation in its Report for 1932 states that 'in every instance it proved to be less expensive to abolish malaria than to treat it with quinine'.

In Singapore, the average death rate from all causes during the period 1892–1911 was 42·33 per mille, and reached 50·91 in the last year, after which anti-malarial work was started. In 1932 the rate had fallen to 20·12 and in 1933 to 19·66. This very marked reduction is attributed mainly to the beneficial results of the strenuous campaign against malaria.

'As elsewhere the removal of malaria has been followed by lowered death rates from other diseases, and larger numbers of children have survived. Had the sex proportions and ages of the population and the death rates between 1912 and 1932 remained the same as between 1892 to 1911, upwards of 100,000 additional deaths would have been recorded. While other public health measures have contributed to the lowering of the death rates, the chief measure was the anti-malarial work, which reduced the great annual malaria wave' (Watson, 1935). 'In 1932 the Health Officer states that malaria is no longer a serious problem in the town area' (Christy, 1935).

As the result of anti-malarial measures in Kuala Lumpur, the true malaria death rate which was 9·7 per mille in 1907, was reduced to 5·8 in 1912, to 4·2 in 1913, to 3·9 in 1914 and to 3·7 in 1915. The expenditure, mainly for drainage, was $185,000 during the period 1907–1915 (Hoffman, 1928).

An official handbook of the Malayan Section of the British Empire Exhibition of 1924 states that 'the railway town of Gemas, which two years ago was a hotbed of malaria, is now a healthy station and a saving of $50,000 a year has been effected'. 'Singapore, Kuala Lumpur, Seremban, Taiping, Klang and Port Swettenham are all cases of successful anti-malarial drainage'. Gammans (1925) also records the great improvement in the health of Port Dickson.

The good results of anti-malarial measures are shown in the classical examples of Port Swettenham and Klang, where Watson (1921) did such brilliant work. As previously recorded (*vide ante* p. 477), immediately after it was opened for traffic in 1901, malaria became so severe at Port Swettenham that, within 2½ months, orders were received to close the port, temporarily at least. By extensive anti-mosquito measures, Watson (1921) was able to convert the place into a comparatively healthy area within a short time.

As a result of this work, the total deaths annually fell from 582 in 1901 to 133 in 1905. The admissions to hospital in Port Swettenham and Klang also decreased from 610 in 1901 to 22 in 1905, while in the surrounding, uncontrolled area they rose from 197 to 622. The number of sick certificates fell from 236 (equivalent to 1,026 days) in 1901 to 4 (equivalent to 30 days) in 1905. In 1901 the number of cases of malaria treated in hospitals, as in-door and out-door patients, was 1,772 among a population of 3,500. On the other hand, in 1933 the number of cases acquiring infection with malaria inside the Sanitary Board area of Klang and Port Swettenham was only 117, among a population of 34,290. The cost of the works during the period 1901–1905 amounted to 52,360 Straits dollars or about Rs. 90,000 per annum, and this was practically all used for permanent work (Watson, 1921, 1935). According to Rose (1919), these results were accomplished at a cost of Rs. 150 per acre at Klang, and Rs. 750 per acre at Port Swettenham. The great financial interests at stake

justified this relatively high expenditure. There is, however, little doubt that, if our present knowledge had been available, the work could nowadays have been done at much less expense.

The dire effects of malaria upon the town of Ismailia in the Suez Canal have already been described (*vide ante* pp. 477-478). In the year 1901, there were 1,990 recorded cases of malaria in this town, during 1902 the cases fell to 1,551, although anti-malarial measures were started only in that autumn. As a result of the work, only 214 cases were recorded in 1903, 90 in 1904, and 37 in 1905. During the next three years no fresh cases were reported as contracted in this town (H. C. Ross, 1911). Rose (1919) states that this work cost initially about Rs. 3 per head in Ismailia, and the recurring cost was about Re. 1.

The Nederlands Indies Medical and Sanitary Service (1929), and Walch and Soesilo (1935), have reported upon the beneficial effects of scientific anti-larval measures in the coastal towns of Java and Sumatra. Apart from the effects on morbidity and mortality, there was a great fall in the spleen rates. The latter authors instance the town of Tegal especially, where the death rate has fallen to 18 per mille, whereas prior to the malaria-control operations it was 33. Russell (1933) and Morin (1935*a*) record good results in towns in the Philippines and in Indo-China, respectively.

Several cities and towns in India have reaped the benefits of active anti-malarial operations.

During 1908, malaria was very severe in Bombay City. This was investigated by Bentley (1911*b*) and, as a result of his recommendations, active anti-malarial operations were instituted in 1911. While the special Malaria Department was in existence, 'the incidence of malaria in Bombay was greatly diminished, in spite of a very considerable amount of apathy, and even active opposition, encountered by the staff in execution of their duties' (Covell, 1928). The malarial incidence was reduced to such a degree that this department was disbanded in 1918. This 'turned out to be a short-sighted piece of false economy'......'the incidence of malaria again began to increase and, in June 1922, the heads of about 40 commercial houses in the Fort area sent a petition to the Corporation, drawing their attention to the serious increase of the disease in their neighbourhood'. Christophers (1924) drew special attention to the menace which this disease was producing to the economic conditions of the city.

'Latterly in Bombay there has been a very ominous increase of malaria in the city itself. Should such conditions increase, as they well may do, in one way or another, almost imperceptibly perhaps, but every day and in every way, to parody a popular phrase, malaria must oust in the long run human activity, until in place of a once active and prosperous commercial community there will remain but a pallid remnant dragging out an existence of temporary exile in a decayed tropical metropolis—like the dreams of some Wellsian romance' (Christophers, 1924).

As a result, it was necessary to re-start a special malaria department, and, 'as was natural, a very large proportion of the work which had been accomplished had to be commenced over again' (Covell, 1928).

Covell (1928) made a very detailed study of the malarial situation in Bombay, and estimated that the city was losing not less than Rs. 50 lakhs annually from the effects of this disease alone. Following upon his recommendations, very active measures against malaria have resulted in a great

improvement in the malarial conditions of Bombay. The Malaria Department had, however, to wage an uphill fight against much local opposition before this result was achieved.

Before the Imperial City of Delhi was started, Hodgson (1914) made a detailed malaria survey of the area, and put forward recommendations designed to protect the new city from malaria. A number of these recommendations were acted upon, with the result that 'the conditions in many parts of the area are now unrecognisable in contrast with their former conditions' (Christophers, 1930). In addition to the original problems, since the building of the new city, others have arisen, mainly man-made and largely avoidable, and these have added considerably to the factors already responsible for malaria in this area (Covell, 1934).

Because of the increasing prevalence of malaria, in 1927 Senior-White (1930) was called upon to undertake an exhaustive survey of the malarial conditions. He formulated appropriate anti-mosquito measures for the Imperial City, and, although many of these have been disregarded or neglected, those undertaken did much to improve the conditions*.

Within the last few years the city of Calcutta has been menaced by the spread of that dangerous Anopheline, *A. sundaicus* (*A. ludlowi*). As the result of the recommendations of Covell (1932), the Government of Bengal, the Corporation of Calcutta and many of the business interests threatened, have considered it to be a financially sound proposition to initiate and carry on a wide campaign against the danger which menaces this city. The benefits obtained must have more than repaid the expenditure.

Phillips (1924) has reported upon the results of anti-malarial measures conducted in five towns in the United Provinces. Saharanpur is the most striking example of the benefits of such a campaign, which was, however, paid for by the Government and *not* by the municipality. The work consisted of drainage operations and a restriction of irrigation in the vicinity of the town. The spleen rate in this town, when the operations started in 1909, was 70 per cent, in 1923 it had fallen to 7 3 per cent, and in 1929 to 3 per cent, while in a neighbouring village it was still 82. The average 'fever' mortality during the period 1899–1908 was 44 7 per mille per annum and the average birth rate 38·2, while during the period 1913-1922 these were 30 4 and 50 1 respectively. The work cost Rs. 3,50,000 in 15 years, amounting to 6¼ annas per head per annum of population (Malaria Commission, League of Nations, 1930).

'It will thus be seen that an enormous improvement has been brought about at Saharanpur as far as the incidence of malaria is concerned, as a result of the anti-malarial measures carried out here, results that will bear comparison with those obtained almost anywhere in the world' (Phillips, 1924). 'Apart from this (restriction of irrigation) the thoroughness with which the sources of Anopheles were ascertained and the recommendations carried out, gives these operations a very definite character of municipal improvement, than which nothing appears to be more hostile to malaria' (Christophers, 1930).

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*The history of the action taken on these anti-malarial recommendations, the necessity for which has been stressed by many workers, has been fully discussed by Covell (1934), and commented upon by a reviewer in the *Tropical Diseases Bulletin* (1935). Neglect of many of these measures has been responsible for the failure 'to create a malaria-free enclave for the Imperial City, which would also be of value indirectly as an example to the rest of India'—the declared official intention at one time.

In Nagina and Kosi, although the recommendations were not carried out in full, it is highly probable that a great permanent improvement has been made in the malariousness of these towns (Phillips, 1924; Christophers, 1930).

In 1922 a scheme was started to reclaim a large portion of the Back Bay at Bombay by filling it in, mainly by means of material dredged from another portion of the Harbour. On certain occasions in the past, such reclamation and subsequent operations (building) in Bombay have been associated with severe outbreaks of malaria (Bentley, 1911*b*). Warned by these previous experiences, 'in the case of the Back Bay Reclamation Scheme, advice was asked regarding steps to be taken to prevent the possibility of such result on the present occasion. The action advised was to engage throughout the course of the work a malaria officer who should maintain a constant and close watch over the operations and take such steps as might from time to time be required to control the breeding of anophelines'......'Colaba, where the chief centre of operations was situated, has not only not suffered any exacerbation of malaria incidence but, owing to the combined action between the reclamation and military authorities, from a place with a high incidence among troops living there, has become almost free from malaria. These operations, in my opinion, owe their effectiveness to the fact that an adequately trained officer was put in charge with no other duties, fully supported by the engineering staff, and kept supplied with what was necessary in the way of funds as the occasion for such expenditure rose' (Christophers, 1930). This story is a very different one from those of previous works of this nature carried out in the vicinity of Bombay (*vide* Bentley, 1911*b;* Covell, 1928).

The operations at Ennur in 1912–1914 greatly improved the malarial conditions there (Christophers, 1930), but unfortunately during more recent years these have been neglected to the detriment of the health of the inhabitants (Rao, 1929*a;* Malaria Commission, League of Nations, 1930).

The malarial conditions in Mercara and other places in Coorg were investigated by McCombie Young and Baily (1928). As a result of this work, extensive anti-malarial operations were started, and have been carried out actively since then. The recent reports show that a very great improvement has occurred in this area as the result of these measures.

The large convict settlements in the Andaman Islands suffered very severely from malaria. The cause of the trouble was found by Christophers (1912) to be due to the presence of a very dangerous mosquito (*A. sundaicus*) which breeds in brackish water. As the result of his recommendations some of the settlements were moved to healthy sites, and many of the dangerous swamps were filled, where these were of relatively small size and near settlements. The beneficial results were very striking (Christophers, 1930; Covell, 1927).

Under the auspices of the Rockefeller Foundation and of the Mysore Government, Sweet and Rao (1934) carried out some extensive anti-mosquito operations in Mysore State. This work was based mainly upon the use of Paris green as a larvicide. They came to the following conclusions :—

'From our experience, and under conditions prevailing in Mysore, it seems possible to give the following estimates of the expense of adequate anopheline control with Paris green. In individual villages of from 500 to 2,000 population such control work will cost 2 to 6 rupees per head of population; from 2,000 to 5,000 population, from 12 annas to 1·5 rupees per head; from 5,000 to 10,000, from 6 annas to 1 rupee per head; in cities above 10,000 population control work would cost from 6 pies to 6 annas per head'.

The cheapest control was obtained in Bangalore City, 'where the work cost just under 6 pies per head and well under 1 per cent of the normal receipts of the municipality' (Sweet and Rao, 1934). As a result of this work the malaria rate and the malaria death rate per 1,000 have been about halved from 1929 to 1932.

At Kyaukpyu in Burma, a successful anti-mosquito campaign has been in progress for 4 years. 'The result is a very marked improvement in the health of the residents and the town now has lost its notoriety for malaria' (Cotter, 1934). The spleen rate, which was 31·25 per cent in 1930, had fallen to 9·54 in 1933. At Kalaw, the rate fell from 15·44 per cent, before anti-malarial measures, to 4·46 in 1933.

From the evidence available, it is clear that the control of malaria in most urban areas is a paying proposition, and that, apart from the humanitarian and social considerations of the benefits conferred by such work, the disease almost certainly causes a financial loss greater than the sums needed to eradicate or control it under very many conditions.

Although many cities and towns in India have achieved a considerable degree of malaria control by means of organised anti-mosquito operations, in many cases such results have only been attained after a great struggle, or when the operations have been financed from outside sources. Such advances have been hampered not only by active opposition, due to 'ignorance of the serious handicaps imposed by malaria and the ease with which they can be profitably overcome' (Fuchs, 1922), but, as specially stressed by the Malaria Commission of the League of Nations (1930), by the Royal Commission on Labour in India (1931), and by Covell (1934), even by deliberate apathy and wilful neglect of expert advice, although the expenditure could be afforded.

(*b*) THE BENEFITS OF MALARIA CONTROL AMONG SPECIAL SETTLED AGGREGATIONS OF PEOPLE.

These anti-malarial operations have been carried out mainly to diminish those very heavy financial losses which have been described as occurring to agricultural, industrial and commercial undertakings in malarious localities (*vide ante* pp. 449–480). This control work is aimed chiefly at the protection of labour forces which are engaged for such industries or undertakings, and the maintenance of whose efficiency is of vital importance to financial success. In numerous instances, such measures would not be economically possible for an ordinary population of the same size situated under similar malarious conditions. Without such anti-malarial measures some of these commercial undertakings could not be run profitably, while some of the engineering works could not have been completed, or only at a very enhanced expenditure, in the absence of measures for the protection of the labour force against malaria.

(1) COMMERCIAL AGRICULTURAL UNDERTAKINGS IN THE TROPICS.

His Excellency the High Commissioner for the Federated Malay States said at a meeting of the Federal Council in 1927, 'It must be quite obvious to all who are acquainted with the conditions that prevailed in the Malay Peninsula during the concluding decades of the nineteenth, and the opening years of the present century, that developments such as the rubber industry, which in so short a space of time has spread over so enormous an area, would have been totally impossible unless the danger of malarial infection had first been successfully combated' (Watson, 1935).

'Money and time invested in the health of a tenantry that cannot or will not take care of itself is one of the safest investments from a business standpoint that a plantation owner can make' (Johnson, 1926).

'We believe that the effective control of malaria would bring about a radical transformation in the health conditions of the plantation areas (of India). One result would be to increase the effectiveness and contentment of the labour force' (Royal Commission on Labour in India, 1931).

As malaria is mainly a disease of rural areas, naturally agricultural undertakings are often those most seriously handicapped by malaria, through its action upon the efficiency of their labour forces (*vide ante* pp. 451–466).

The influence of malaria upon the economic working of large agricultural undertakings in tropical countries has become well recognised by many business concerns during the last few decades. In Oriental countries, very many of the commercial interests connected with large tea, rubber and coffee plantations, now consider it a paying proposition to undertake special measures to protect their labourers and staff from the harmful effects of the disease.

The benefits which have accrued to the rubber plantations of Malaya are well known as classical examples of the commercial value of such work (Watson, 1921).

In the Annual Report of the Ross Institute for 1931 it is stated that in Malaya, 'from figures relating to rubber estates totalling 100,000 acres in area, it was proved that the cost of production of malarial estates was 25 per cent higher than those on which malaria had been controlled'.

Watson (1935) records that on the Seafield Rubber Estate the percentage of the labour force treated was 939 in 1914, and this fell to 1·08 in 1924. The capital cost of the subsoil drainage used to abolish mosquitoes on this estate from 1911–1918 was about £8,000. This author estimated in 1920 that 'apart from the saving of human life and conservation of "bark", the cost of the subsoil drainage has probably been repaid several times over in the past five years'*.

Christy (1935) gives details of the results of anti-malarial work on another rubber estate in Malaya which was very malarious in 1911. In the latter year the death rate was 232 per mille and the cost of producing a pound of rubber was $1·09 (F. O. B.); in 1932 the death rate was only 1·1 and the cost of producing a pound of rubber was 7·53 cents. Barrowman (1934) reports upon the extraordinary results produced on the rubber plantations of Carey Island by anti-malaria measures†. He records that, with a population of over 5,000 persons scattered over an area of 26 square miles, the malarial infection rate for the last 5 years has only been 0·1 per cent per annum. 'This combination of measures is so successful and so unobtrusive that the whole population goes about its daily work doing nothing it would not do elsewhere, and unconscious that, but for the control in force, the Island would be one of the death traps of the tropics'.

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*'What was probably as intensely malarious a place as exists on the face of the earth, one which for the Indian labourer was uninhabitable except at an unjustifiable cost of life, is now so free from malaria, although not completely free, that Indians come to it readily, a large and efficient labour force lives on it, and a further improvement in health may be anticipated with confidence' (Watson, 1921).

† A description of the estate and of the anti-malarial measures used is given by Watson (1921), (pp. 83–85).

The same worker (Barrowman, 1934) says that, as a result of a 30 years' campaign against malaria, infantile mortality has fallen from 900 to 130 per mille, and the birth rate risen from 5 to more than 200 per mille of adult females due to anti-mosquito measures. An estate where such results have been obtained must be on the highroad to achieving that ideal of estate managers, *i.e.*, to be able to produce its labour force locally, and so do away with the very expensive method of recruitment from outside sources (*vide ante* pp. 461–463).

'Controlling mosquitoes at from $25 to $30 per acre is a sound business investment on rubber estates that pay more than 100 per cent in annual dividends and in a region in which the death rate among coolies on unprotected estates runs as high at times as 176 per thousand. Such expenditures, however, are practical only under exceptional conditions' (Rose, 1919).

The economic loss caused to certain rubber estates in Ceylon was investigated by Ross (1926), who pointed out the financial benefits which would follow malaria-control work.

'I have no doubt that similar figures (of economic loss) can be obtained from all the estates in the island; and, besides the waste of productive labour, numerous other expenses are caused by the disease—hospital and other medical expenses, maintenance of families, and so on. My main argument is, therefore, why waste thousands a year in consequence of malaria when a few hundreds a year may suffice to prevent or at least diminish it? Even if the preventive measures cost as much as the malaria costs (which will probably be very seldom the case), the humanitarian benefit in the saving of sickness and death will still turn the scale in favour of prevention. There is no alternative left—either prevent your malaria or continue to lose thousands a year in consequence of it'.

The beneficial effects of anti-malarial measures have been reported also from Indo-China by Morin (1935, 1935*a*) and by Morin and Robin (1933), from their observations and experiments on agricultural undertakings and plantations in that country. Morin (1935) considers that it is ten to twelve times as costly to allow malaria to prevail as to control it.

Russell (1933) reports successful control with Paris green on the haciendas of the Philippine Islands.

'At del Carmen the hacienda has continued this work with great satisfaction to the owners. In 1932, seven years after the inauguration of this method of control, the incapacity of labourers due to malaria ceased to be a problem'. (The cost of this work was about Rs. 1·5 per head per annum.)

The malarious conditions of the localities where the tea industry is located in Northern India are usually very bad. The Malaria Commission of the League of Nations (1930), in speaking of the problem of these estates in the Terai and hill districts, states :—

'Conditions greatly improve if the immigrant population is well housed, well fed, well cared for medically and sanitarily, even without any special anti-malarial precautions. With the latter, many a "death trap" has been changed into a health resort. That a country as unhealthy as the Bengal Terai, where in the sixties Lady Canning contracted a fatal infection by spending one night there, is now the scene of flourishing agricultural industries shows that it can be settled by Europeans and Indians without paying too heavily in health and life and, as in Southern Assam, even with impunity if thorough anti-malaria precautions are taken'.

Many workers have reported upon the economic value of properly conducted anti-malarial campaigns in reducing the amount of malaria upon tea estates in Bengal and Assam, and the monetary value of such work. The following are a few of those recorded :—

Forsyth (1928) reports that the malaria attack rates on seven tea gardens in the Tezpur District of Assam, with a population varying from about 6,600

to 8,600 fell from 250 per cent in 1915 to 121 per cent in 1919, as the result of prophylactic quinine. When anti-mosquito measures were combined with the treatment of cases, the rate fell to 63 per cent in 1921 and 81 per cent in 1922.

The Malaria Commission of the League of Nations (1930) state that in Cachar, Ramsay found that by anti-larval measures 'in eighteen estates under his supervision, with a total population of about a thousand each it has been possible in two or three years' time to reduce the spleen rate from 70 to 10 per cent, to double the amount of labour done by the same number of coolies and to reduce greatly the quantity of quinine dispensed. This has been done at an expenditure of about 1 rupee per head'.

Strickland and Murphy (1932) record the results of drainage and other anti-malarial measures on certain tea estates in South Sylhet, Assam. These measures resulted in a marked decrease in the spleen rates, in the number of malarial cases, in the average daily sick, and in the infantile mortality, while the birth rate increased. The drainage works also led to the reclamation and improvement of much land for agriculture.

The Manager of one estate writes—'Yearly the incidence of malaria among the coolies is becoming smaller. The benefits are many. A healthier and more contented labour force; a higher birth rate and a lower death rate. The time when the malarial scourge was at its height, usually coincided with the time when on most gardens every available worker was required. Now, not only are the workers available, but they are much more able to do their daily task. This can readily be appreciated by anyone who has been the victim of malarial fever, and can recall the before- and after-effects of a bout of such'.

'That these benefits can be proved by actual figures in itself speaks volumes; and when one takes into consideration the fact that this anti-malarial work has only been in progress here for three years, it is not too much to expect that within a very few years more, the malarial scourge will be a thing of the past'.

The financial losses which malaria was causing to certain tea estates in Assam were carefully investigated by Rice and Savage (1932), and these authors pointed out the financial savings which would arise from certain anti-malarial operations.

Ramsay (1934) has given details of the excellent results obtained on tea gardens in Assam by different doctors when using malaria-control measures :—

'Dr. Fraser has sent me the following figures, which show the results of anti-larval measures in his practice. The total sick days in his practice in 1927 amounted to 249,306. As the anti-larval work progressed, this was reduced year by year until in 1933 the sick days amounted to 141,687. This represents a reduction of 107,610 sick days during 1933 as compared with 1927. The cost of maintaining sanitation and general health of labour forces in 1929 was Rs. 1,81,854. In 1933 these costs were reduced to Rs. 1,00,683, a reduction of over Rs. 80,000 annually. To this, of course, must be added the greater efficiency of the labour force as a whole'.*

Dr. Manson 'gives us figures for two gardens which were formerly very unhealthy. In 1931 on one estate the cases of sickness from all causes totalled 3,971, and deaths, both adult and children, amounted to 50. In 1933 these were reduced to 1,512 and 24, respectively. For the other estate, in 1931 the cases of sickness were 3,931 and deaths 33, and in 1933 were reduced to 1,555 and 22, respectively'.

Christy (1935) reports that in a group of tea gardens with a population of about 13,000, the admissions to hospital from all causes were 23,226 in 1930 and these fell to 15,141 in 1932.

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* Christy (1935) records the number of labourers on this estate as over 17,000. This being so, the average annual sick days per individual have fallen from 14½ to 8½, as the result of these measures.

As the result of anti-mosquito work undertaken to protect the staff of the Sahmaw Sugar Plantations in Burma, the spleen rate was reduced from 73 per cent to 29 per cent in 4 years (Cotter, 1934).

It is impossible to enter here into the details of the many other records of the financial and other benefits which have been reported as the result of anti-malarial measures in connection with large agricultural undertakings in the tropics. Their number is legion, and they come from almost every malarious country. Those quoted above are but a few to indicate the good results which have been obtained.

That scientific and up-to-date anti-malarial measures, more especially anti-mosquito ones, are usually sound and paying propositions, under the conditions prevailing in large estates, is becoming very widely recognised by the large commercial interests who have to employ labour forces for the cultivation of tea, coffee and rubber, both in India and in many other tropical countries. More and more of these undertakings are starting malaria control work. These shrewd business men realise that anti-malarial measures are not only a most valuable aid in solving those labour problems which have been discussed earlier in this paper, but are also a sound financial investment, whereby the cost of production is markedly lowered and profits substantially increased.

(2) Industrial undertakings in the tropics.

The malariologist 'has first to convince the shrewd industrialists, the proprietors of large industrial concerns, who refuse to think of anything but rupees, annas and pies that it pays to eradicate malaria and thus to justify his position. To do this successfully he has to estimate first, the precise economic loss caused by malaria, to the industrial concern which appoints him' (Rao, 1928).

Malaria control in connection with industrial and commercial undertakings in malarial localities is now becoming widely recognised as a financially sound investment. The progress made in anti-malarial work by such interests has been much greater than that of civil communities.

'Individual and groups are notoriously slow in applying to themselves the knowledge that has been gained of preventive medicine. But industrial organisations and business concerns, looking at the subject from an entirely different angle, have been quick to see the importance of protecting the health of their employees as a business proposition solely. They have been told that malaria, through sickness and decreased efficiency, causes a greater economic loss to the malarious sections of the South (of the United States) than all other preventable diseases combined--approximately a billion dollars a year. This malaria awakening of the Southern commercial interests from a purely business standpoint may not be prompted by what some would term the highest motives, but it is backed by shrewd business sense and offers the most immediate prospect of accomplishing malaria control on an extensive and permanent basis' (Fricks, 1920).

Earlier in this article, numerous instances have been cited where uncontrolled malarial prevalence has given rise to severe financial stress in, and even the abandonment of, promising commercial undertakings, both industrial and agricultural. The sequence of events in such cases has been stressed by Le Prince (1932).

'Let us assume that in one of these progressive countries a group of bankers or prominent business men started to develop a plant for the manufacture of structural steel or some other important industry. If imported skilled labor should be used, then unless the directors of the industry take adequate precautions, it may not be long before the workmen become infected (with malaria), become inefficient; the operation costs climb out of all proportion to what they should be, skilled labor may have to be temporarily replaced

by unskilled labor, accidents will follow and financial difficulty may follow much quicker than is anticipated'.

The success of such enterprises in malarious localities depends very largely upon the availability of sufficient and efficient labour, and under these conditions the labour problem is almost entirely synonymous with the malaria problem. If the latter can be solved economically, the former usually presents comparatively few or no difficulties*.

(i) Manufacturing enterprises.

The beneficial effects reported by commercial interests in towns in the United States, where control measures had been completed, were mentioned previously (pp. 94–98). Other tributes to the value of such work are not wanting from individual companies who have undertaken such measures at their own expense.

'The Burton-Schwartz Cypress Co., Perry, Fla., U. S. A., referring to its anti-malarial work, states "In our opinion the efforts and expense are fully justified in the increased labor efficiency, and we anticipate keeping up our program as long as we are here. We would strongly advise every mill in the country to do the same thing"'. The General Manager of the Longville Lumber Co., Longville, La., writes—'The writer has held for years that one of the greatest assets of a manufacturing business is the health of the crew; that you can not make any money with a man when he is sick, therefore keep him well; that you can not make as much money with a man when his family is sick, because you do not have his thoughts and attention on the work, as it is occupied with considering the condition of his family, therefore keep his family well, and to that end we provide every safeguard that we know of' (Fuchs, 1922). Lowe (1920) states that the commercial world now recognises the financial value of disease prevention and that the Southern Settlement and Development Company is taking active measures in malaria propaganda and control.

In relation to the results of such measures, the Annual Report of the United States Public Health Service for 1920 also says, 'Industries in infested areas report from 10 to 40 per cent increased output after control measures are in operation. Chambers of Commerce report new industries establishing branches in towns where elimination of malaria has rendered local labor efficient, and factory managers report that, since malaria-control measures were carried out, there is a more steady supply of labor, that the quality of labor has improved and the earning capacity of the laborer increased. Lumber-mill corporations have willingly contributed from $1,000 to $10,000 towards local anti-malaria campaigns, and state it pays them well to make such an investment'.

When the malarial incidence increased in Bombay City, the heads of about 40 commercial houses were so concerned, that they sent a petition to the Corporation, drawing attention to the seriousness of the condition (Covell, 1928). Similarly when the menace of severe malaria approached Calcutta in 1931, business concerns considered that their interests were so seriously threatened that a deputation from the Bengal Chamber of Commerce waited on His Excellency the Governor of Bengal, and drew his attention to the need for control measures. Some businesses in the most exposed areas formed an Anti-Malaria Society to deal with the danger in their vicinity (Covell, 1932).

* The Annual Reports of the Ross Institute and Hospital for Tropical Diseases, London, and the booklet by Christy (1935) give very interesting information upon the beneficial results which have been achieved by anti-malarial measures in connection with commercial and industrial undertakings.

Several of the large mills, situated in the area invaded by malaria, have also undertaken special anti-mosquito measures to protect their staffs.

The importance of the protection of the forces engaged in industrial occupations in malarious localities has been widely recognised in many parts of the world. If the proposed solution of the economic problem in India by a widespread industrialisation of its population is to be successful, the needs for anti-malarial measures to protect the workers will become a necessity, apart from the financial benefits which will accrue from such measures (Sinton, 1936).

The English staff of the Rio Tinto Mines in Spain and their families, numbering a total of about 170 persons, were protected by anti-mosquito measures, with very good results, as shown in Table VIII (Macdonald, 1911).

TABLE VIII.

Results of anti-malarial measures at the Rio Tinto Mines.

Year.	Anti-malarial measures taken.	Cases of illness.	Cases of acute malaria.
1896 ..	No prophylaxis	89	25
1906-07 ..	Prophylaxis	61	2
1907-08 ..	"	64	0
1908-09 ..	"	78	0
1909-10 ..	"	80	1

The measures were then extended to control of the ravines round the workmen's villages. The work was mainly drainage and filling. 'The improvement in the health of the people has been most marked'.

'In former years departments with 2,000 men at times had hundreds incapacitated by fever, and difficulty was sometimes found in maintaining the service. Now, although some cases still occur, fever never rages to the extent it did formerly. Villages which were recognised as hotbeds of malaria, and consequently avoided by the workmen, have been rendered comparatively healthy again. The cost of these measures in Rio Tinto and its environs is less than £100 per annum' (Macdonald, 1911).

Very successful results were obtained from anti-mosquito measures at the Roan Antelope Copper Mines in South Africa. The mines have now abundance of labour. These results have been tabulated by Christy (1935) (Table IX).

TABLE IX.

Results of anti-malaria measures at the Roan Antelope Copper Mines, South Africa.

DEATH RATES PER 1,000.

Year.	EUROPEANS.	AFRICANS.		
	All causes.	Disease.	Accident.	TOTAL.
1930 ..	19·6	30·9	3·4	34·3
1931 ..	9·7	16·0	3·2	19·2
1932 ..	7·3	7·7	1·7	9·4
1933 ..	5·3	5·2	4·8	10·0

The great damage which malaria causes among the labour forces in the mining industry in the Singhbhum area has already been recorded (*vide ante* pp. 468–471). Knowles (1930) gives an account of the expensive and extensive malaria-control operations which were used at the Noamundi Mine, and the good results which followed the work. 'It is significant, however, that there were 18 cases of blackwater fever on this mine in 1928; there have been none since the control commenced'. Successful anti-malarial operations in other mines in the same area are recorded.

(*ii*) *Railway systems.*

The harmful effects of malaria upon all aspects of railway work in the tropics have been discussed in detail earlier in this paper (*vide ante* pp. 471–476). The first workers who made any systematic attempt to ameliorate these unfavourable conditions appear to have been the Italians in connection with the Adriatic Railways.

The following table (Table X), given by Celli (1911), records the effects produced by anti-malarial measures on the incidence of, and the labour inefficiency caused by, this disease.

TABLE X.

Malaria along the Adriatic Railways.

Year.	Percentage of cases of malaria.	Days of mean duration of cases of malaria.	Mean of days of illness lost every year per person.	Observation.
1888–1901	69·92	7·88	5·48	Without prophylaxis.
1902	44·93	6·99	3·12	Mechanical prophylaxis.
1903	30·32	6·25	1·89	,, ,,
1904	33·10	7·53	2·48	,, ,,
1905	39·44 *	7·64	3·01	,, ,,
1906	27·65	7·09	3·39	Mixed prophylaxis.†
1907	22·70	8·58	2·41	,, ,,
1908	15·79	9·67	3·17	,, ,,

* An epidemic year. † Mechanical *plus* quinine prophylaxis.

This table shows the benefits which followed upon the measures taken, and Celli (1911) goes on to state that the system of 'mixed' prophylaxis is in use on the Italian Railways, and 'is obligatory for contractors of public works'.

Since Celli made his report, the measures against malaria among the employees of the Italian Railways have been much extended, showing that the work is considered to be sound economically. This work and its results have been described by Dr. Filippini in a lecture given at the Advanced School of Malariology at Rome*. The campaign has now been further augmented by the introduction of anti-larval measures in certain areas. Apart from the reduction in mortality and morbidity, the malaria-control work has resulted in a great reduction in the number of days lost per employee from malarial

* A translation of this lecture has been published by Senior-White and Newman (1932), to which the reader is referred for further information.

sickness, a very important economic aspect of the case. Filippini calculates that in 1880 each man lost annually 4·5 days work, while in 1923 the proportion was reduced to 0·3—an enormous gain to the management.

Filippini records that similar anti-malarial methods have now been adopted on railway systems in malarious parts of Austria and France. Malaria-control measures have also been started on railways in Spain, Roumania and Bulgaria. On the Madrid, Zaragoza and Alicante Railway in Spain, Macdonald (1911) states that, in 1901-02, before anti-malarial measures (screening and quininisation) were begun, the number of cases of fever was 631, while, after the control came into force, the numbers fell to 306 in 1903-04, and to 190 in 1905.

It is, therefore, clear that the directors of these European railways consider that anti-malarial operations are a sound financial proposition.

The financial losses due to malaria among the employees of railway systems in the United States have also led to active measures of prevention. Leathers (1918) notes that some of the local railways in the Southern States have recognised that the eradication of this disease is a paying proposition, not only by conserving their labour, but also by contributing to the prosperity of the district served by the railway. There is some very well-organised anti-malarial work in Texas, on the St. Louis-South Western Railway, in places where malaria was a serious factor (Senior-White and New Man, 1932). The savings effected by anti-malarial measures on the Cotton Belt Railway have been noted in Table VII.

Thomas (1911) draws special attention to the losses, financial and otherwise, which railways operating in South America have to bear, as the result of the neglect of anti-malarial measures.

'All through the Amazon region, where large engineering works have been undertaken, the old familiar story has been repeated. Not only has money been wasted, but many lives have been sacrificed by the neglect of the promoters to realise the dangers of malaria and Anophelines' (Thomas, 1911).

When such precautions have been taken, Cruz (1911) reports completely successful campaigns in connection with the construction of the Itatinga Railway, and the North-West Brazil Railway, and the extension of the Brazilian and Northern Minas Railways through malarious parts of Brazil. The Argentine Railways have also started anti-malarial work among their employees (Senior-White and Newman, 1932).

The satisfactory results of such a campaign on the Central South African Railway are reported by Bostock (1911). As the result of screening measures, the actual daily average numbers sick fell from 13·06 in 1904 to 1·38 in 1905. During the building of the Zambesi Bridge, it was anticipated that the malarial prevalence among the staff stationed in this notoriously unhealthy area would be serious. Appropriate precautions were taken to prevent such trouble, and Watson (1935) reports that, since the work began in 1931, there has only been one case of malaria among a British staff of 100 individuals.

These instances of the benefits of malaria control on railway systems show that, in many foreign countries, it has been realised that such work is economically sound and is a paying proposition.

The important part which malaria takes in lowering the efficiency, inhibiting the development, and reducing the profits of railway undertakings in

malarious localities of India, has been discussed in detail earlier in this paper (*vide ante* pp. 471–476). Clemesha (1917) drew special attention to the need for anti-malarial operations in connection with railway systems in India. To give but a couple of examples of the financial loss caused, Senior-White and Newman (1932) estimate that the Bengal-Nagpur Railway is losing more than 7 lakhs of rupees annually due to this one disease alone, while Rao (1928) calculates that, in a single district of the Eastern Bengal Railway, malaria sickness among the staff cost from about Rs. 25,000 to Rs. 36,000 annually during the years 1924, 1925 and 1926. It is not surprising, therefore, that these two railway systems have considered it economical to start very active campaigns for the protection of their employees against malaria, and have appointed expert malariologists to carry out this work.

The malaria-control measures used during the construction of the railway line from Vizianagram to Raipur (*vide ante* pp. 471-472) afford a most striking example of the benefits of such work.

'In the construction of a new line through the very highly hyperendemic country north of Vizagapatam, an organised system of selected camping grounds associated with anti-mosquito work was carried out. This is the first time in India that an attempt on these lines has been made to protect labour, employed on railway construction under such circumstances'.

As results of the measures undertaken, Senior-White (1928) reports that the daily incidence of malaria never reached 2 per cent of the total labour strength*, a figure which the engineers considered negligible. 'It may be claimed, in fact, that construction through this hyperendemic tract has proceeded with a lower morbidity than any large engineering work hitherto undertaken in India. The mortality from the disease has been *nil*'.

'The results, however, were not obtained at any inordinate cost. Once the organisation was got into working order which took between three and four months, the upkeep charges,......only amounted to Rs. 18 per mile of construction per month, a negligible amount in the vast sums involved in railway construction' (Senior-White, 1928)†. The same author gives several concrete instances to prove that this expenditure was justified.

Good results were also obtained by malaria-control measures among the labour force engaged in constructing the railway line in the Kangra Valley in 1927-28.

The beneficial effects of proper control measures in connection with these large railway construction projects, are in marked contrast with the high morbidity, mortality, and financial loss which have occurred in many other parts of the world, when such work has been undertaken without proper precautions

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*'At any rate, the sick rate, due to fresh cases of malaria, was not high—less than 1 per cent per month. In some other camps, where the contractor refused to carry out the prescribed anti-malarial measures, the sick rate ran so high that the coolies were deserting one after the other and the work in these camps had stopped completely. Information regarding these unsatisfactory conditions was naturally welcomed by us as affording some insight into the actual value of such costly measures. Without such information, a sceptical critic might have maintained that the work would have gone on as well without all that oiling and paris-greening. The discomfiture of the contractor, who evidently shared the views of the critic, is sufficient answer to the criticism' (Malaria Commission, League of Nations, 1930).

†'Total cost to protect the camps alongside the 60 miles of railway within the danger zone, 57,600 rupees in four years, being 0·48 per cent of the total costs of the construction of this portion of the line' (Malaria Commission, League of Nations, 1930).

(*vide ante* pp. 472-473). Apart from the humanitarian aspect of the case, the financial saving must have been enormous.

It is not only in these extensive construction projects that anti-malarial measures have proved of value. Clemesha (1917) and Christophers (1930) point out the good results of malaria-control work during the construction of the Sara (Hardinge) Bridge over the Ganges. Senior-White and Newman (1932) estimate that anti-malaria work during the re-girdering of the Bhanwar-Tonk Bridge saved a sum of Rs. 70,000.

The tunnelling work at Saranda in the hyperendemic Singhbhum district of Chota Nagpur gave another proof of the beneficial results of malaria-control work. This undertaking was started without proper precautions to protect the labour from malaria, and, as a result, the work was almost completely disorganised (*vide ante* p. 473). Following on malaria control, 'one of the most notoriously deadly spots in the whole of Singhbhum has been rendered practically malaria free' and the work proceeded apace (Senior-White, 1928).

'The original cost of the survey and preliminary drainage works, including salaries, was in the neighbourhood of Rs. 3,000; thereafter maintenance, including salaries and oil, has averaged Rs. 92 per week, but the inspector has time on his hands for attendance on other stations, and when these are taken up and part of his salary allotted to them, the cost will fall to Rs. 39 weekly' (Senior-White, 1928).

Apart from the ravages which malaria causes among labour aggregations during engineering operations of various kinds on railway systems, it also gives rise to great disability and financial loss due to sickness and disability among the staff stationed in malarious areas (*vide ante* pp. 471–476).

The Malaria Commission of the League of Nations (1930) has called attention to the beneficial results obtained by anti-malarial measures in several stations. 'The protection of the railway area in Waltair (an important railway junction) conducted along exactly the same (anti-larval) lines, costing 3,637 rupees annually to protect a population of about a thousand, is particularly convincing, as the total sick rate of the protected population never rises to 1 per cent monthly, whereas the personnel and families living outside the protected area show a sick rate of at least 8 per cent in the malaria season, although the medical attendance is the same for both'. In Siliguri, as the result of doses of quinine given thrice weekly and of anti-larval measures, the sick rate decreased from 40 to 17 cases per month in August, September and October.

The stations along the important Ambda-Jamda Branch of the Bengal-Nagpur Railway are notoriously malarious. 'The railway company, taught by experience, has spared no cost to protect the personnel of the stations, this being the only means of keeping the line, which is particularly important because of the iron and manganese mines in the area, in working condition'. Anti-larval measures were used within a radius of ½ mile of these stations. 'The costs are comparatively heavy. In one station, they were 12,000 rupees capital outlay and 2,500 to 3,000 rupees annually to protect a personnel of 461. But, in cases like these, they are not prohibitive' (Malaria Commission, League of Nations, 1930). The results obtained at Dangaoposi station on this line have been recorded by Senior-White (1928). About 4 months after this station was opened, work there came almost to a standstill because of malaria*.

*** A description of this outbreak has been given previously (*vide ante*, p. 475).**

Following the completion of a permanent anti-malaria scheme, 'the success achieved was most striking, for malaria almost ceased to exist at Dangaoposi'. The spleen rates had fallen from 79·6 in 1925 to 32·2 per cent in 1926. 'I think the reduction amply justifies the outlay and proves the financial as well as the scientific practicability of control at stations on open lines'*.

Christophers (1930) reports the instance of Lumding Junction in Assam, where malaria was so severe that the question of abandonment was considered. Anti-malarial work has, however, done away with such an eventuality.

Some very interesting results are reported by Sladen (1927) at Ishurdi station on the Eastern Bengal Railway. Following upon an anti-malarial campaign the number of certified sick days among a staff of 617 fell from 3,207 from all causes, of which 2,565 were due to malaria in September 1925, to 696 and 53 respectively in the same month in 1926. This worker considers that a sum of Rs. 8,377 was saved in this one station during the year, as the result of the control measures.

Suhrawardy (1928), in his pamphlet on 'Anti-Malarial Measures on State Railways', draws attention to the good effects of malarial campaigns on railways. He points out that 'railways have always looked upon the wage-earning capacity of their employees as a practical business proposition and therefore have been early in taking the field in the matter of malaria control'. 'The ultimate aim of a railroad malaria-control programme is to eliminate malaria wherever it is serious enough to become a charge against operating expenses or to result in a loss of revenue or dislocation of work'. He goes on to say 'the experimental stage of anti-malarial work is long passed and special expenditure for this work on our State Railways should, without demur or question, be voted for, and passed by the members of the Central Legislature'†.

It is clear, from the instances reported above, that proper malaria-control work is a paying proposition in connection with all railway systems operating in localities where the disease prevails. This important fact is being realised, more and more, by the directors and engineers‡ of large railway systems in tropical countries.

(3) Miscellaneous aggregations of people.

'Gigantic commercial enterprises have been undertaken and then given up on account of the havoc wrought by this scourge (malaria), and it has only recently been recognised that the medical man must precede and prepare the way for the engineer and the labourer' (Phillips, 1929).

The severe malarious conditions which may arise, in the absence of proper precautions against malarial infection, are now well recognised under conditions where 'tropical aggregation of labour' occurs. Such conditions are most common in connection with large engineering works in tropical climates, and the evil effects of these outbreaks, on both the sanitary and the financial

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* The further history of anti-malarial operations at this station has been given by Senior-White and Adhikari (1934).

† The beneficial and economical results of malaria control in relationship to all aspects of railway work in India have been specially discussed by Sladen (1927), Senior-White (1928), Suhrawardy (1928), and Senior-White and Newman (1932), to which articles the reader is referred.

‡ Mr. W. H. C. Kelland of the Bengal-Nagpur Railway has contributed an interesting and useful Appendix, entitled 'Malaria Control on Constructions', to the paper of Senior-White and Newman (1932).

aspects of such undertakings, have been pointed out earlier in this paper. The public health aspects of this subject have been stressed by Christophers and Bentley (1909), by Clemesha (1917), and by Sinton (1933). However, in recent years, astute commercial men are beginning to realise that 'it is cheaper as well as quicker to organise a scientific force to combat malaria, and to have such a force in operation before any attempt is made to import labour and commence work' (Thomas, 1911). Many good examples of the benefits of such precautions have occurred in modern times.

In instances where the aggregations of labour will be located in one area for a long time, more expensive methods of mosquito control, such as various permanent drainage operations of major or minor size, have sometimes been found less expensive eventually than temporary measures of control. They also assist in reducing the recurring costs of the latter. These more permanent operations are specially useful and economically sound when the area occupied by the labour force is afterwards to be used for a permanent settlement, as was done in the reclamation of the Pontine Marshes in Italy (Ilvento, 1934). In other instances, it has been considered more sound financially to rely upon measures of a temporary character to control the ravages of the disease, and prevent excessive labour inefficiency.

(*i*) *Large engineering undertakings.*

The construction of the Panama Canal is usually cited as the finest example of the value of preventive medicine on the successful issue of a large and important engineering project in an unhealthy and malarious area. The French company were driven out by malaria, yellow fever, and dysentery, and were glad to sell their rights to the United States as a bargain. The sickness and death rate were so high that they decided the canal would not be worth the sacrifice, even if they could manage to complete it against the enormous obstacles raised by disease.

When the Americans took over charge, the cases of malaria admitted to hospital per 1,000 employees of the Panama Canal and the Panama Railroad, were 514 0, and in 1906 they were 820 9 (Chamberlain, 1928); in other words about half the labour force was continuously suffering from malaria of such *severity as to require hospital treatment*. In 1927 the rate per 1,000 was 10·7 among a labour force of 13,560, many of whom acquired their infections outside the sanitated areas. The latter figures, be it noted, include *all cases* of malaria *whether or not admitted to hospital.*

The deaths from malaria per 10,000 employees in 1906 were 87·8, from which time there was a steady fall to a rate of 0·9 in 1916 (Hoffman, 1928), while Chamberlain (1928) reports that, up to the end of 1927, there had only been two deaths in the last 7 years, among an employed labour force ranging between 10,500 and 13,500 persons.

These figures give an example of the enormous saving of life and suffering which properly executed anti-malarial measures may produce. Apart from this, is the economic saving, and Gorgas states that it is not extreme to say that it was only such measures which enabled the Canal to be built (Mégroz, 1931). Even the efforts and the enthusiasm of Gorgas and his assistants would have been useless but for the whole-hearted support of their Government, which

realised that without such measures the Canal could only be built, if at all, at enormous sacrifices of lives and money.

The cost of this malaria-control work was relatively very high in the Canal Zone. Gorgas estimated that the money spent on anti-mosquito measures was about Rs. 6 per head per annum (Bentley, 1925)*. Such an expenditure was justified by the enormous national importance of the work to the United States, and no expense was spared when this was recognised. However, 'as a necessary part of digging the canal, the cost of sanitary operations on the Zone is negligible; but as a part of normal public health work such measures are feasible only in limited areas in which there is dense population to support them' (Rose, 1919). As a result of the knowledge of malaria-control work which has been gained in the last 30 years, it is certain that this work could be carried out less expensively nowadays.

'Clearly such enormous sums as this are altogether outside the scope of practical politics (save under special conditions). And though Gorgas's splendid achievement merits the highest praise, it does not afford example that can be followed in Bengal in present circumstances' (Bentley, 1925).

Atkey (1926) reports upon the effects of anti-malarial measures in reducing the morbidity and mortality among the large labour force employed in the construction of the Sennar Dam in the Sudan. The measures employed were (*i*) elimination of mosquitoes, (*ii*) screening, (*iii*) segregation of more highly susceptible personnel, and (*iv*) quininisation in some cases. During the season 1919-1920, the malaria attack rate among the more susceptible Egyptian labourers was 33 per cent, with a death rate of 31·0 per mille. As a result of the measures mentioned, these fell during the season 1924-25 to 1 and *nil* respectively, among the workers at Sennar. During the latter season, at an outlying locality where anti-mosquito measures had been neglected, because of high pressure of other work, a sharp epidemic occurred which threatened to bring the work to a standstill. The necessary remedial work was carried out, and the epidemic rapidly subsided.

The construction of the head-works of the Sarda Canal in the notoriously malarious Terai of the United Provinces, and of the Mettur Project on the Cauvery River, Madras, afford good examples of the benefits of anti-malarial works in connection with large irrigation works in India.

The head-works of the Sarda Canal are situated in the very malarious Terai of the United Provinces, where from 3,000 to 9,000 labourers were aggregated (Clyde, 1931). It was found that 'in the first year of the works, before anti-malarial measures were started, work had to be closed down in April because 96 men out of every 100 imported were down with fever at one time. Contractors refused to carry out the work and one after the other cleared out, and it was realised that unless active measures were taken the head-works would never be completed' (Clyde, 1931). Extensive anti-malarial measures were of necessity undertaken, and Phillips (1929), who was in charge of the early medical arrangements, points out how the completion of the undertaking was 'facilitated and quickened by anti-malarial measures at the head-works of the canal......These measures have had the effect of increasing and

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*'The cost of operations in the Canal Zone—our most conspicuous demonstration of malaria control—was on the average for a period of five years $365,000 annually. With an average population of about 100,000 for the area treated, this represents an annual *per capita* cost of $3.65' (Rose, 1919).

prolonging the working season from about three months to nearly eight months, and those of you who have had experience of work in the jungle realise how important the element of time is in such undertakings'. During their tour in India, the Malaria Commission of the League of Nations (1930) also commented upon the beneficial results of the anti-malarial operations carried out in this area.

That the financial saving caused by the measures taken against malaria was enormous, is shown by the statement made by the Chief Engineer, Sir Bernard Darley, to the Legislative Council (Clyde, 1931).

'It is very difficult to estimate the economic value of the malaria staff at Banbassa in rupees, annas and pies. The work that has been done has certainly enabled the working season to be extended from 15th April to say 15th June, *i.e.*, 2 months each year, or 10 months in 5 years; in other words the work will thus be able to dispense with the services of about half its divisional staff a year earlier, a saving of probably Rs. 50,000.

If, however, we take into account the value of delivering water one year earlier for irrigation, the monetary value of anti-malarial work would probably run to half a crore of rupees.

Secondly by keeping the labour fit, it has been possible to inspire confidence, and good contractors have come forward to take up the work at lower rates than was deemed possible at first.

I have gone over the estimates and putting this saving at Re. 1 to Rs. 2 per 100 cubic feet of masonry, etc., this saving might be fairly estimated at Rs. 1,50,000—that is, of course, assuming that any contractors would have taken up the work at all under the adverse circumstances obtaining before the malarial staff got to work. Indeed, it is very doubtful if the Sarda Canal head could have been built at all without the expert help we have received from the medical department'.

The Mettur Dam on the Cauvery River was built in a less malarious area than that of the U. P. Terai. 'In the original villages in this area, now occupied by the works, the spleen rate was 45 per cent at its maximum'......'The total population, including coolies' families, varies from 15,000 to 17,000'. The population in this area was protected by the drainage and oiling of mosquito breeding places, and by quininisation. 'The result of the work is shown in the low malaria rate of 1 or 2 per cent of indigenous cases (of malaria) per year, and the low spleen rate of 19 per cent in the camp, which this same year suffered from an outbreak of malaria. The cost of maintaining the whole of the sanitary department is 30,000 to 35,000 rupees per annum (being 0·04 per cent of the total cost of the work), of which 12,000 rupees are spent on anti-malarial coolie gangs and oil' (Malaria Commission, League of Nations, 1930). 'Investigation in 1925 revealed that the original inhabitants of the area were found to be severely infected, both splenic index and parasite rates being very high. During the succeeding years, although the number of workers, many of whom may have been good carriers of malaria by themselves, has exceeded 10 to 12 thousand, malaria as a source of disability has been almost negligible' (Rao, 1929*a*).

The great disorganisation of labour, and the sickness and mortality, which have occurred during the construction of docks and harbours in the tropics have already been noted.

The conditions in the vicinity of the lagoon, where it was proposed to construct the new Vizagapatam Harbour, were those which would be very suitable for the propagation of *A. sundaicus,* that dangerous malaria-carrying mosquito which was responsible for such very severe and fulminant malaria during the construction of the Ocean Harbour at Belawan in Sumatra (Schuffner and Hylkema, 1922). The villages along the edge of the construction work

already showed a hyperendemicity due to the presence of other dangerous species of anophelines. Under these conditions it was deemed necessary to take adequate anti-malarial precautions to protect the labour force recruited for the work.

'The objects in view were threefold. It was desirable that the city of Vizagapatam should not be adversely affected, either by the construction operations, or by the adverse conditions that might accompany the creation of the Harbour. It was necessary to take precautions to prevent a serious outbreak of malaria among the labour employed and housed by the Harbour Authorities on the site of the works. And it was desirable that the completed Harbour should be safeguarded from the breeding of anophelines, and be free of danger to shipping using the port' (Rattenbury, 1934).*

During the whole period of the construction of the harbour works, in an area where malaria was hyperendemic, and where the conditions for the excessive breeding of dangerous anophelines prevailed, no serious outbreak of malaria occurred to hamper the progress of the construction or to cause an abnormal malarial incidence, either among the workmen or the inhabitants of the surrounding areas. On the other hand, there is good reason to believe that the permanent anti-mosquito measures (filling, drainage, etc.) carried out in the vicinity of the Harbour have done much to improve the local malarial conditions there†.

During their tour in India, the Malaria Commission of the League of Nations (1930) inspected the control measures and reported—'This work, which shows its good results by the declining number of malaria cases treated in the hospital of the port, is of particular interest, because it has been undertaken, not as a consequence of a serious outbreak of malaria, but to prevent such an outbreak among the present labour force and especially among the personnel of the port after it has been opened'.

(ii) *Forces, military and civilian.*

During the military operations forces of men are frequently located temporarily in areas where malarial infections are easily acquired. Disastrous results have often followed when precautions have not been taken to prevent the disease (*vide ante* pp. 486–488). Under most such conditions, permanent measures of mosquito eradication have frequently not been possible or advisable‡, but in many areas during the Great War, the sanitary services on both sides have done much to alleviate the sickness among their forces by temporary measures of drainage, protection from mosquito bites, quininisation, etc.

In more permanent camps much was achieved by scientific anti-mosquito measures, for example at Taranto Camp in 1917, where malarial infections were spread to many of the troops passing through (Robertson, 1920). Here 'the anti-mosquito measures adopted in 1918 and 1919 practically kept the camp free from anopheles in 1919......So free did the camp become that prophylactic quinine and the use of mosquito nets were discontinued. Among the

* A summary of the work done and its results have been given by Satyanarayana (1934).

† The Chief Engineer of the Harbour construction reports that the measures 'have been highly successful, and there is no doubt that the construction of the Harbour with the accompanying malaria control, which has been instituted over the Harbour area, has been of great benefit to the adjoining city as far as malaria incidence is concerned' (Rattenbury, 1934).

‡ Le Prince (1919a) has given an account of the methods employed to protect military cantonments and shipyards in the United States during the Great War.

personnel of over 1,000 in 1919 there were only nine possible camp infections, and it was probable that the infection had been contracted elsewhere' (Wenyon, 1923). Austen (1919) has given an interesting account of the anti-mosquito measures carried out during the campaigns of 1917-18 in Palestine, and, in the discussion which followed this paper, several other officers gave their experiences of the benefits of such work under war conditions.

The conditions under which the army lives in cantonments in peace time are often very like those of towns. The American Army by means of drainage and screening measures have been able to give their troops in most places a high degree of protection, as for example in Texas and Panama. At Camp Stotsenburg in the Philippine Islands, Russell (1933) states that the use of larvicides has been very successful as an anti-malarial measure. Laveran (1907) reports that among troops stationed in a very unhealthy area near Rome, who were protected by screening and quinine prophylaxis, only 1·74 per cent developed malaria, while among troops who were screened but got no quinine the rate was 2·67. Among the Japanese troops in Formosa, of one group of 115 men who were properly protected against mosquito bites, none developed malaria, while in the rest of the battalion (646 men), the malarial morbidity was 44·09 per cent and the mortality 1·12 per cent. Laveran (1907) gives other examples of the value of anti-malarial measures.

The great value of measures which protect troops from mosquito bites has been recognised, and is accepted by most authorities. Russell and Nono (1934) have 'expressed the opinion that subsequent to 1906 (in the Philippine Islands), nets appear to have reduced the incidence of malaria in the Army by about 75 per cent'. The proper use of the nets was very strictly enforced before this result was obtained.

In poor countries like India, the Army Department do not always consider that they can afford some of the more highly expensive measures of permanent mosquito control, which have been used in richer countries*. They have often relied upon measures of a more temporary and less satisfactory nature to protect their military forces. The universal use of mosquito nets, and up-to-date treatment have done much to lower the malaria sickness rate in the Army. The health of many stations has been improved by drainage and anti-larval operations. The screening of barracks in certain very malarious localities has done much to help in the campaign against malaria.

Hanafin (1928) has given figures to show the beneficial effects of screening of barracks upon the malarial incidence among British troops in certain stations in the Punjab (Tables XI and XII).

At some specially important defence centres, as in the case of the Panama Canal Zone, it has been thought permissible to incur the additional expense needed to undertake permanent operations of mosquito control. The reclamation of the new Naval Base at Singapore is another example. Christy (1935) states that 'anti-malarial work has made it possible to construct and maintain the Naval Base, situated in a very malarial area, with a minimum loss of life'.

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*The Army in India is allotted about 10 annas per annum per head of the military population for sanitary and field works, as compared with Rs. 22 spent in the works at Panama, *i.e.*, about 35 times as much.

TABLE XI.

Comparison between proofed and unproofed barracks in Lahore Cantonment, 1st August to 31st October.*

Year.	British Infantry.				Other British units (unproofed).		
	Average strength.		Malaria admissions.	Ratio per 1,000.	Average strength.	Malaria admissions.	Ratio per 1,000.
1923	588	Unproofed	500	850·34	352	190	539·77
1924	489	"	236	482·62	309	95	307·44
1925	281	Proofed	190	569·40	334	157	470·06
1926	302	"	55	182·12	293	197	672·35
1927	285	"	13	45·61	391	104	265·98

TABLE XII.

*British Infantry Company, Amritsar Cantonment, 1st August to 31st October**

Year.	Average strength		Malaria admissions.	Ratio per 1,000
1923 ..	166	Unproofed	118	710·8
1924 ..	194	"	145	747·4
1925 ..	199	"	122	613·0
1926 ..	146	Proofed	25	171·2
1927 ..	137	"	8	58·4

* These are the months of maximum malarial transmission.

On some occasions, civilian labour forces may be gathered into depôts in malarious areas. Hoffman (1928) (quoting from the Report of the Malaria Advisory Board of the Federated Malay States for the year 1913) points out the remarkable effect of anti-mosquito measures upon the malaria sick rate among the Indian recruits on labour contracts, collected at a depôt at Kuala Lumpur.

The average monthly percentage of cases of malaria treated in the hospital or given sick leave, increased from 37·75 per cent in 1910 to 57·01 in 1911, decreasing to 27·33 per cent in 1912 and to 11·3 per cent in 1913. It is pointed out in explanation of the statistics that 'these figures mean that in 1911, to take the worst case, every Indian at the depôt was in hospital or given sick leave for malaria on an average seven times during the year. Very few places can show a sickness rate to compare with this, and when it is remembered that the men were picked healthy Sikhs and Pathans of a high physical standard it will be realised what the condition of a labor force having a poor physical standard would have been under the circumstances. It may be mentioned that the improvement was obtained notwithstanding the large increase in the density of the population at the depôt subsequently to 1911 when in consequence a large number of men were without the protection of a mosquito net at night. Quinine has only been given to men under hospital treatment or those who come to ask for it'. The improvement was therefore chiefly, if not exclusively, due to the drainage work undertaken by the government or private enterprise.

The results recorded above are examples of the benefits which are derived from various types of anti-malarial measures employed to protect aggregations

of people in malarious areas. They serve to illustrate how modern opinion is now realising that, apart from any humanitarian reasons, it is a paying proposition to spend money upon such work.

(*c*) SUMMARY.

The results recorded above go to show that malaria control in urban areas is usually a comparatively easy problem as compared with rural districts. The fact that a large number of persons are congregated and settled inside a relatively small area, makes the sum available for such work, per unit area, much larger. At the same time, in urban areas the usual necessary sanitary and drainage operations are often inimical to the breeding of dangerous mosquitoes, and urbanisation is usually synonymous with a greater control of waste water. Permanent anti-malarial measures should be undertaken as a normal part of municipal improvement, and such works should have a very early claim upon the finances of towns. Such permanent measures require relatively little upkeep, and, if properly executed, render the majority of the inhabitants safe from malaria, if legislation be enforced to prevent the formation of new man-made sources of mosquitoes.

It has also been shown clearly, in the records given, that successful anti-malarial measures have a very great effect in solving the labour problem, which is such an obstacle to the progress of large agricultural, commercial, engineering and other undertakings in the malarious areas of the tropics. Up-to-date business men have now recognised that the introduction of proper malaria control is not only a sound investment but one that often gives a very large return upon the capital invested.

'For populous communities, for sugar and hemp haciendas, and for military camps, malaria control by means of anti-larval measures is distinctly worth while in the Philippines as elsewhere' (Russell, 1933). An official handbook of the Malayan Government, issued at the British Empire Exhibition of 1924, states 'Malaria prevention is a sound economic proposition where groups of people are gathered together in towns, villages and estates'.

The only conclusion which can be drawn from the evidence available is that, with settled collections of people in malarious areas, anti-malarial operations are a paying proposition.

In most large settled collections of people, 'permanent' measures are usually the cheapest in the long run, while temporary ones mean an annual recurring expense which soon may become greater than the sum needed to undertake 'permanent' operations*. The cost of upkeep of 'permanent' works is small compared with that of temporary ones.

Whether the measures to be undertaken should be of permanent or temporary nature, will depend upon the causes of the malarial conditions and

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*It should be noted, however, that many of the so-called 'permanent' measures, are not so. As remarked by Russell (1933) 'it must be remembered that in the tropics, at least, malarial prophylaxis would have to be carried out year by year during this century and the next. There is no more permanence in sight for malaria control than for road repairs or water sterilisation'. Chamberlain (1929) and Clark (1934) point out that even the enormous measures taken in the Panama Canal Zone have not produced a permanent eradication of malaria. Many of these have to be continued with unflagging watchfulness in order to prevent the enemy re-establishing its foothold. The position is similar in rubber plantations of Malaya. In other words, 'we have scotched the snake, not killed it'.

upon the funds available, and the value economically, socially or otherwise, of the population afflicted. It is, however, clear from the evidence cited that it is a paying proposition to spend all the money which can be raised for the purpose on anti-malarial measures to protect people aggregated in malarious areas. Wherever possible we should follow the dictum of Schuffner, and substitute methods which have a prolonged and permanent action for those which, while giving an immediate and striking effect, are but ephemeral in their results.

(II) RECORDED BENEFITS OF ANTI-MALARIAL MEASURES IN SCATTERED POPULATIONS OR TEMPORARY AGGREGATIONS OF PEOPLE.

So far we have only dealt with the benefits of malaria-control work among special collections of people, such as those of cities and towns, or the relatively stable aggregations of labour employed by industrial and other large undertakings.

Most of the successful control measures mentioned above were started primarily with a view to the eradication of malarial disease, which was interfering seriously with the health or amenities, or the commercial interests, or the progress of the development, social or economic, of the inhabitants of certain special localities. It had been realised by the people, or their representatives, that the benefits derived were worth the expenditure, or else commercial and other undertakings deemed, and found, it a paying proposition and a sound investment, to undertake such measures to increase the health and so the labour efficiency of their staffs.

The best of the successful methods which have been detailed above have been obtained mainly through the application of methods for the destruction or control of mosquito breeding. There is no doubt that, in our present state of knowledge and with the means at our disposal, it is only by such mosquito-control methods that one can hope to obtain results which are likely to be of a more or less permanent nature.

That such schemes for malarial eradication are economically sound for large settled communities is now generally admitted. It is a different story, however, in the case of scattered people, especially the poor rural populations of the tropics. The fine results obtained among the populations of Malaya* and Italy are often quoted as a reproach to workers in India and other tropical countries. It must be remembered that half the population of Malaya lives in cities or large towns* (Williamson, 1935), and about 88 per cent of the agriculturists of the southern, or most malarious, portions of Italy lead an urban existence (Report of the Rockefeller Foundation for 1932). In marked contrast to this, about 90 per cent of the inhabitants of India are located in rural areas. As pointed out by Christophers (1924)—'malaria prevention (by anti-larval methods) for plantations, industrial concerns, towns and cities, and many other circumstances is one thing, a claim that rural malaria "is preventable" and therefore why not "prevented" is simply a quibble of ignorance'.

*** In spite of the enormous improvements which have been made on estates and in towns, malaria is still the most serious disease problem in Malaya.**

'Malaria control through eradication of the mosquito vector is comparatively simple if expense need not be considered. But to control this disease, when expenditure must be kept within the average public health budget, is a far more difficult task. The problem is to bring the control work within the economic means of the community' (or state or body interested) (Rockefeller Foundation Report for 1932).

'Given a *limited* endemic malarial area and *unlimited* funds, any experienced malariologist can formulate a scheme for the reduction, and in many places for the eradication of malaria' (Hehir, 1927).

In malaria control, through the destruction of dangerous mosquitoes, the expense to the community to be safeguarded is roughly proportional to the area and the type of breeding grounds that lie within the limits of the normal range of flight of the insects to the normal environments (especially the nocturnal ones) of the inhabitants. It is obvious, therefore, that the cost of mosquito control per head of population, under any special set of conditions, will increase and decrease inversely with the number of individuals per unit area. The practicability of financing malaria control by anti-mosquito measures will accordingly depend directly upon the amount of money available in proportion to the expenditure needed for the control measures.

As an example of this, the work of Sweet and Rao (1934), in the Mysore State, may be quoted. From the results of their careful investigations, these authors concluded that malaria control by anti-larval measures in cities with a population above 10,000 would cost from 6 pies to 6 annas per head per annum. The cost gradually increased as the number of the population diminished, until they found that in individual villages with a population of from 500 to 2,000, such control work would cost from 2 to 6 rupees per head*.

The Malaria Commission of the League of Nations, from its study of rural malarial conditions in many parts of Europe and elsewhere, came to the conclusion that, save under exceptional conditions, malaria eradication by means of anti-mosquito measures was not a method that, in our present state of knowledge, was within the financial means of scattered inhabitants in rural malarious localities. Where these measures had proved successful in some regions, they had depended either upon some special local condition which could be cheaply remedied, or upon measures paid for by a subsidy from some outside source.

Many other experienced malariologists in different parts of the tropics have arrived at the same conclusions.

Hackett (1929), as a result of his work in Italy and Sardinia, states that—'I think it is justly held that organised larval control is not economical in most, thinly scattered, rural populations. Here the burden must be shifted from the community to the individual'.

Barber and Forbrich (1933), who worked in the irrigated regions of New Mexico, U. S. A., concluded that 'it is difficult to cope with rural malaria by larvicides alone in a region where breeding places are so abundant'....... 'Larvicides may be necessary to do away with a mosquito nuisance, or for local or temporary protection against malaria, but it is doubtful whether they can be profitably used year after year on a country-wide basis'.

As a result of prolonged anti-larval operations in the Philippine Islands, under the auspices of the Rockefeller Foundation, Russell (1933) came to the conclusion that 'it

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*Covell *et al.* (1935) gave details of the recorded cost of anti-larval measures per head of population in certain rural areas in different countries. These workers point out that the lack of funds presents the greatest obstacle to the use of this method in such localities.

cannot be said that there has ever been demonstrated in the Islands a malaria-control project for typical small communities which was within the means of the people'....... 'Paris green or oil will kill anopheles larvæ as effectively in tropical as in temperate zones. But the labor cost, and above all the expensiveness of (expert) supervision* have been real barriers to practical control except in a few populous places'.

The Malaria Commission of the League of Nations (1930), on their visit to India, were specially interested in the question of methods for the control or eradication of malaria in rural areas. After considering the benefits of anti-mosquito work in urban areas, they go on to say 'it is difficult to see how far the experience gained can be used for the control of malaria in rural areas. With the present public health budgets and the inertia of the local governing bodies, we doubt whether it will prove useful, as it only teaches that malaria can be controlled if sufficient money is available'.

'The expensive nature of permanent anti-malarial measures, combined with the financial stringency affecting both Government and the local bodies (in Burma), has made it impossible, except in a few places, to adopt anything more than palliative measures such as the issue of cinchona febrifuge tablets' (Cotter, 1934).

It is clear from the evidence available that, while the eradication of malaria by anti-mosquito measures is an ideal to be aimed at, yet, in our present state of knowledge, such a method is usually beyond the financial means of the majority of the scattered communities which form the bulk of the population in the tropics. In our present state of knowledge, this state of affairs 'really means that malarial control (by mosquito eradication) in India is practically limited to selected groups of population, whose health, for some reason or other, is particularly valuable and particularly threatened by malaria' (Malaria Commission, League of Nations, 1930).

As James pertinently remarks 'no policy can be considered entirely satisfactory that aims at the protection of only a few, however important those few may be, while it leaves the bulk of the inhabitants of a place in the same condition' (Balfour and Scott, 1924).

Although under present conditions there are few countries where it has been considered practicable economically to launch large and expensive schemes, aimed solely at malarial *eradication* among a scattered rural population, yet very much work has been done to *alleviate* the unfortunate malarious state of such people. Many large schemes initiated for the improvement of agricultural conditions by drainage and prevention of flooding, have done much to diminish the intensity of malaria, not only through their effect in decreasing the mosquito population but by the resultant improvement in the economic and social condition of the people.

Much has been done to decrease the mortality and suffering among the people by the more widespread provision of easily available treatment to the sufferers, a scheme which is the first, and a most essential, step in any anti-malarial campaign†. With the spread of education and public health propaganda among the rural population, the beneficial effects of protection from infected mosquitoes, by means of screening of dwellings and of mosquito nets, are being more widely recognised, and the use of these prophylactic measures increased..

*'Needless to say anti-malaria work without a large amount of personal supervision is largely a waste of time and of money, especially in the early stages of organisation. All sanitary work is a question of attention to detail and anti-malaria work is no exception'..... 'As conditions in this country (Federated Malay States) are at present, the success of anti-malaria work must largely depend upon the interest taken in it by the man on the spot, whether he be the estate manager or the district officer' (Gammans, 1925).

† This aspect of the rural malaria problem, with a special reference to India, has been discussed by Sinton (1935).

In most malarial campaigns in rural areas, it is usually by a combination of these anti-malarial measures that it can be hoped to ameliorate the ravages of the disease, until some more economically practicable solution for the problem can be discovered in the future. It is not usually possible, therefore, to evaluate the benefits of any one method separately, and, in addition, the collection of data from an uneducated and scattered population is much more difficult, and the results less reliable, than from the more highly educated and organised communities of towns, or the more disciplined populations of commercial and other undertakings.

The benefits recorded by different workers may be discussed under the headings of—

(*a*) Mosquito control or reduction in rural populations; and

(*b*) Amelioration of malarial prevalence in scattered populations, or among temporary collections of people.

(*a*) MOSQUITO CONTROL OR REDUCTION AMONG RURAL POPULATIONS.

'Malaria is a rural disease. Our cities and towns (in the U. S. A.) have done a good job of mosquito control and have reduced the malaria rate to a very low degree. In the rural sections of the South malaria still exists as our most impoverishing disease' (Stanley, 1932).

'Malaria is the most serious of the impoverishing rural diseases' (Le Prince, 1932).

'A more easy method is to prevent them (mosquitoes) biting one by keeping them away. But only the minor part of the population, namely the richer and, therefore, the least attacked, can enjoy this benefit' (Celli, 1911).

That the ravages and economic burden of malaria fall most heavily upon the rural population is universally admitted. The Malaria Commission of the League of Nations (1930) considered rural malaria to be the most important problem of India. The effect of this disease in preventing the colonisation of large tracts of very fertile lands, and in hindering the exploitation of the natural wealth of many areas, has been felt for a very long time. While it was recognised that the development of these tracts would add much to the wealth and prosperity of the nations concerned, most attempts to reclaim or to develop these regions have been unsuccessful until comparatively recent years. The ravages of malaria upon the labour element were so great, that, in the absence of control, these ventures were very often found to be either catastrophes or economic failures. With a realisation of the facts that the labour problem in such localities is the malaria problem, and that the control or amelioration of this disease is the basis of all really successful exploitation in these areas, much progress has been made in recent years. This has been more especially the case where a rapidly growing population has made it necessary to provide more room and employment and an increased food supply (*vide* Sinton, 1936).

As has been stressed above, it has not yet been found economically possible for large rural populations to finance widespread measures for mosquito eradication, unless under some special conditions. One must remember that it may be accepted as a general axiom that in the tropics, at least, 'the malarious are poor and the poor malarious'. Widespread measures of agricultural and social 'bonification', to be discussed later, have done much to diminish the mosquito danger and improve the social, economical and health conditions, but these cannot be looked upon as measures originally financed purely or mainly for the eradication of malaria.

Under certain conditions, it has been found possible to eradicate, or greatly diminish, the prevalence of malaria in rural areas by anti-mosquito measures which were suited to the means of the population. The circumstances have, however, been very special.

As has been found by the Malaria Commission of the League of Nations, by the workers of the Rockefeller Foundation, and many other eminent malariologists, there is as yet no panacea, through mosquito destruction, which is financially possible, for the eradication of malaria in the majority of rural areas.

The successful measures reported have in many instances not depended entirely upon mosquito destruction, but have been aided by other anti-malarial methods.

The Island of Brioni in the Adriatic Sea, once an important province of the Roman Empire and Venice, and still showing vestiges of Roman civilisation, was for many centuries uninhabitable because of malaria. Between 1800 and 1899, a succession of owners made fruitless attempts to eradicate the disease, but it was only in 1899, when Koch took charge of the sanitation of the island, that it was done successfully. Between 1901 and 1902, when it was declared malaria free, the value of the island rose from $40,000 to $1,000,000 (Anderson, 1927).

Kligler (1928) reports successful campaigns in Palestine where anti-mosquito measures were combined with widespread treatment and propaganda. 'In 1922, the year before extensive control operations were undertaken, figures compiled in the districts selected for work showed that each month an average of 5·7 per cent of the population had malaria. In 1923, the average monthly rate had been reduced to 2·9 per cent, by 1924 to 1 1 per cent, and by 1925 to 0·8 per cent'.

Scharff (1935) reports upon the excellent results obtained by anti-larval measures in certain rural areas and villages of the northern part of the Malay Peninsula (Penang and Province Wellesley). In the neighbourhood of Penang, 'the effect has been to transform the appearance of villages. In place of miserable and weakly children there are now sturdy youngsters. Squalor that was induced by sickness has given way to comfort and good health'. In the villages controlled in Province Wellesley, there has been a marked drop in the spleen rate among the school children.

The cost of these works was not, however, paid for directly from the incomes of the population benefited, so they cannot be considered as an example of individual effort.

In certain exceptional circumstances of climate, physiography, and species of mosquito, it has been found economically practicable to free limited rural areas almost entirely of malaria. The case of certain parts of the Adriatic Coast, where the mosquito breeding was limited to isolated ponds ('lokvas'), is an excellent example. Here, by the use of the larvicidal fish, malaria has been stamped out. Extensive larvicidal operations, with Paris green, are being carried out in certain parts of Yugo-Slavia, to protect rural inhabitants, and the results reported are favourable. Here again the breeding places are limited and usually well defined. They have not that constantly changing and increasing character which is so common in the tropics, and which requires so much costly expert supervision to ensure control.

At present, anti-mosquito operations in rural areas, if undertaken at all, are rather the burden of the individual than the community.

Hackett (1929) reports successful results in Italy, but the conditions were very different from those found in the tropics. The effort can hardly be considered as a purely individual one, or of widespread application among ignorant rural populations.

'An instructed and fairly prosperous individual can protect himself by screening and anti-larval measures, as we have proved in a portion of the Roman Campagna called the Valchetta. The houses are screened and each owner applies Paris green regularly to breeding places on his own property, under inspection by the Experimental Station. Malaria has been almost eradicated by this method in three years. This, however, requires co-operative effort on the part of the land-owners of the area' (Hackett, 1929).

Sweet and Rao (1934) have suggested that, by the use of Paris green control, it may be financially possible to use anti-mosquito measures in certain types of rural area in India.

'Another possibility in rural areas is presented by a compact area in which there are a number of large villages. In such an area it may be possible to carry out efficient control for from 8 annas to 1·5 rupees per head, depending on the population included, with a staff of one field labourer per village (with extra men for replacement, mixing Paris green, etc.), one technical inspector for 10 villages, and one malaria officer for a maximum of about 60 villages' (Sweet and Rao, 1934).

About a decade ago in certain malarious parts of Lower Bengal, Anti-Malaria Co-operative Societies were started. Although these efforts are partly subsidised from outside sources, the local people were largely responsible for the work and finances of these undertakings. The societies included a large amount of local anti-mosquito work in their programmes, and combined this with other measures against malaria. A considerable degree of success has been reported from these efforts. Since that time this movement has spread to many other provinces, and the work has been taken up by Boy Scout Organisations, Junior Red Cross Units, schools and other local associations, as well as by the new Departments of Rural Reconstruction, in combination with other measures to diminish the ravages of malaria.

Russell (1933) thinks that possibly some such methods may help to solve the question of rural malaria in the Philippine Islands.

'There is no evidence that malaria control (in rural areas) will ever be achieved in the Philippines without anti-larval measures. As has been pointed out above, this presents a real problem in economics, and attempts are being made to work out a solution. It is possible that free labor, well supervised, may be made available by the schools. Older seventh and eighth grade boys can apply Paris green to mosquito breeding areas as field exercise in biology and hygiene. Such an experiment is in progress. Other communities are trying unskilled labor, employing one man permanently to apply Paris green to streams, day in and day out, year after year. Such work is done casually, no doubt, but in *time* it should reduce the incidence of malaria-carrying mosquitoes' (Russell, 1933).

This campaign of educating the younger generation in the dangers of malaria, and the means and necessity of taking all possible steps to diminish these, should do much to further the practical effects of any crusade against this, the most important and dangerous, disease of the tropics. It should also help to limit the extension of the 'man-made' malaria which is often such an important factor in many localities.

It is clear that, from the evidence available, as yet no measure of malarial *eradication* by mosquito control *per se* has been found, which is within the financial means of the ordinary small communities and scattered population of

the rural areas of the tropics, however beneficial and paying such measures may prove to be under exceptional circumstances. Such anti-mosquito measures may, however, play a very useful part when combined with other measures for the amelioration of malarial disease among rural populations. This would probably be so especially if the individual can be made to realise the importance of such measures and to apply them.

(b) AMELIORATION OF MALARIAL PREVALENCE IN SCATTERED POPULATIONS, OR AMONG TEMPORARY COLLECTIONS OF PEOPLE.

There are many instances on record where large drainage works have been responsible for enormous benefits to the malarious conditions of rural populations. Most, if not all, of such steps have been taken not primarily as anti-malarial measures but rather to obtain an extension or improvement of agricultural conditions, *i.e.*, agricultural bonification. It would not have been economically practicable to incur such a heavy expenditure purely for public health reasons*. In many instances the introduction of these measures has been forced upon a country by the need to find room and employment for a rapidly expanding population, and the necessity to augment the locally grown food supply of the country (Sinton, 1936).

Apart from such large schemes of bonification, all we can advise, in our present state of knowledge, are efforts to ameliorate the lot of the unfortunate malaria-ridden people of rural areas, by measures which will reduce the mortality, the morbidity and the suffering amongst them, and will decrease that labour inefficiency which malarial sickness causes.

Under certain conditions, the removal of the inhabitants to more healthy sites may be undertaken, but is usually very expensive. By measures of 'rural reconstruction' there should be an increase in the education of the people, whereby they will take steps to protect themselves against mosquitoes, either by measures of local eradication of breeding places and prevention of the formation of new ones, or by protection from insect bites by the use of screening or mosquito nets. Such measures should be pushed, but in the present state of education in India and many other parts of the tropics, it will probably require several decades before they show any very marked effect. They are, however, ideals to be aimed at, and, any extension of primary education should be combined with instruction as to the dangers, and methods for the control, of this disease.

As pointed out above, it will probably require many decades before such educational measures can be spread to any considerable proportion of the illiterate rural masses of India. In the meantime a million persons are dying annually and over 100 million suffer each year from the disease in this country.

One cannot humanely allow the people to continue to suffer and die, while giving them only the assurance that, after an indefinite period of time, probably years, measures for the eradication of the mosquito will begin to show their beneficial effects upon the mortality and morbidity of the population. *Whatever measures be taken to eradicate malaria under any conditions, the first and most indispensable one is that these should always be combined with the*

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*It is now recognised in Italy and many other malarious countries that, to obtain the full benefits of such agricultural 'bonification', it is necessary to ameliorate or to eradicate the malarial conditions among the local people at the same time.

provision of proper treatment for the sick and suffering. Such therapeutic measures alone cannot hope, with the drugs at present at our disposal, to eradicate malaria from a locality. For this purpose they must be combined with measures for the destruction of the harmful mosquito. Treatment is only a step towards the amelioration of the condition of the people, by reducing the mortality, morbidity and suffering among them and increasing their labour efficiency, and so their general prosperity. This means an increase in both their standard of living and their social and educational levels. When this has been done the people will then be in a better position, physically, mentally and economically, to initiate and carry out those more radical measures of malaria control, which in their previous miserable condition they had neither the energy, the education nor the money to start.

Among such poor and scattered populations, one may consider the benefits of

(1) Schemes of bonification;
(2) Schemes of widespread treatment; and
(3) Miscellaneous anti-malaria measures.

(1) SCHEMES OF 'BONIFICATION'.

'Malaria disappears before good agriculture and sanitation' (Minett, 1921).

'Malaria may be classed among the social diseases of a country. It is now recognised to be, as a rule, most prevalent and of greater severity in countries of low social and economic status. Its prevalence diminishes in proportion as the economic and social levels are raised'....... 'Malaria, like many of our social and community diseases, may gradually disappear with the improvement of economic conditions, the more intensive settlement of the country, and the intellectual development of its inhabitants. Progress of civilisation is accompanied by the regression of malaria' (Kligler, 1928).

'The economic improvement represented by progressive cultivation supplemented by the passage of the necessary sanitary laws, which usually follows enlightened public interest, is in the long run the most effective means of abolishing malaria' (Report of the Rockefeller Foundation for 1932).

'It should be clearly understood that failure to eradicate the mosquito is not a condemnation of drainage schemes, which, aside from the incidental effect upon the problem of mosquito control, are essential projects in land reclamation with important hygienic and agricultural objectives. Economically and from the point of view of public welfare, land reclamation is of the greatest value in countries where the pressure of the agricultural population is constant' (Report of the Rockefeller Foundation for 1934).

It has been well recognised for many years that, with improvements in agriculture and in the economic and social well-being of the inhabitants of certain malarious localities, there has resulted a very marked decrease in the prevalence, or even a disappearance, of this disease. The most striking results have been noticed in temperate zones (England, Holland, France, Northern Italy), but, in the more malarious areas of the tropics, the success of such measures has been much less marked, unless augmented by some other more active measures of attack upon the disease or its causal factors.

It is a very fortunate circumstance for the inhabitants of rural areas that effective drainage*, which plays such a predominant part in mosquito eradication, is also required for the fullest agricultural development in most circumstances, and that the conditions which lead to agricultural decline are very

* On the other hand, imperfect or ill-advised drainage may, under certain conditions, be both inimical to agricultural prosperity and progress, and favourable to increased malarial prevalence (*vide* Bentley, 1925).

often identical with those which cause an increase in the prevalence of malaria. Because of this happy coincidence, many very large drainage schemes have been financed and launched in attempts to improve agricultural and economic conditions, at an expenditure which would not have been considered from a purely public health standpoint.

These great schemes for the improvements of agricultural and economic conditions have been very largely exploited by the Italians under the name 'bonification' ('bonificazione'). Although by their direct effects they may diminish the mosquito prevalence in some instances, in others this is not so, and there may be even an increase of these insects. Sometimes, however, although there is an increased prevalence of mosquitoes, the dangerous species may be markedly diminished, or the improved conditions may make the inhabitants less liable to attack by them. The most successful effects of 'bonification' in malarious regions have been achieved where the larger engineering measures have been supplemented by other methods of attack on the disease.

'As people become healthier their energy increases and they become still more prosperous, consequently more land is cultivated and drained, cultivation is cleaner and drainage better, houses screened and malaria is further reduced' (Carter, 1919).

Except when the scheme is combined with measures of a purely anti-malarial nature, its action is indirect and relatively slow, and may even be unsuccessful in regions of high endemicity. The indirect mode of action of these large schemes of agricultural 'bonification' *per se* on malarial prevalence, may be summarised as follows*:—

With improvement in agricultural conditions a previously poverty-stricken people become more prosperous, and this condition of prosperity has usually a markedly adverse effect on many of the causal factors of a high malarial incidence. Good and nourishing food becomes more abundant. The people build better houses, less attractive for the shelter of mosquitoes. Overcrowding is diminished. Domestic animals increase in number, and are housed under conditions which tend to attract mosquitoes away from man. With better living conditions, health improves, and overwork is less frequent. With increased prosperity, the sick can afford to avail themselves of prompt and better treatment of their illness. The standard of education rises, and with it a sanitary conscience begins to develop. The more intelligent make attempts to prevent malaria by the use of screening and mosquito nets, and by the abolition of local conditions giving rise to mosquito breeding. With the natural increase of the population following upon better health conditions, the demand for immigrant labour diminishes, with a resultant decrease in the introduction of foreign strains of malarial parasite and of non-immune individuals into the area. With increased prosperity and a higher standard of education, the people realise the benefits of malaria control, and can either afford to take more adequate steps to eradicate malaria, or to pay for such steps.

'Millions of acres in India to-day are not producing what they should because they are not properly drained. Money spent in anti-mosquito drainage is often rapidly repaid by the natural resources made available.

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* These have been discussed in greater detail by Sinton (1933). The subject is also dealt with by Sergent and Sergent (1921), Sergent (1922), Ilvento (1934) and many other workers.

Drainage of this magnitude is always a serious undertaking; even in small areas, drainage scientifically carried out means expenditure of funds which at first sight appears disproportionately high to the prospective results.

The salutary effect on malaria which follows drainage of a previously malarial district is not entirely due to the drainage, for it is well known that drainage *per se* is an anti-malarial measure that takes a long time to operate beneficially. There are other factors, such as improved sanitation and water supply, better housing, healthier lives, general levelling of the surface, impermeable roads, abolition of collections of water that previously existed, and all the other attributes of industrial prosperity, that must be taken into account before we can estimate the intrinsic merits and influence of drainage alone' (Hehir, 1927).

Nowadays the necessity of combining anti-malarial measures with all schemes for agricultural bonification in malarious localities, is becoming much more widely recognised in progressive communities. By these methods not only may the attainment of prosperity be considerably hastened, but the ultimate success of the scheme may be dependent on such measures.

The early Italian works of bonification, to reclaim the very fertile but malarious and poorly cultivated areas of Italy, were based almost solely upon large schemes of agricultural drainage or reclamation ('agricultural bonification'). Later these methods were supplemented by widespread campaigns of quininisation. Although by such measures certain areas were made habitable, it was found impossible to stamp out malaria by these methods alone, and the disease still continued as a scourge which prevented the complete development of many localities where there was a high prevalence of malaria. The Italians then realised that, to obtain the full benefits of 'bonification', it was absolutely essential to combine anti-malarial sanitation with their large engineering works. This became so well recognised that, by the Act of 1933, it was laid down that authorised schemes for 'bonification' must cover 'the planning, financing and operating not merely of hydraulic and agricultural works, but also the health services required to preserve the health of labourers, peasants and superintending staff, without which every attempt must end in disaster. Such is the legal conception of the *bonifica integrale*' (Ilvento, 1934). This principle has now been applied to many large reclamation works in Italy, in such death-traps as the Pontine Marshes, the delta of the Tiber and the valley of the Po.

Various unsuccessful attempts had been made for 25 centuries to reclaim the very fertile Pontine Marshes. In 1927, work was begun again in this area, and the combined methods detailed above were introduced. As a result of this campaign, while there were only 1,800 persons resident there in 1923, in 1934 the number had risen to 40,340, *i.e.*, an increase of 2,300 per cent, and all these persons, both peasants and workmen, had come in from Italian districts that were immune from malaria. 'Out of nearly 10,000 people belonging to the families of settlers, there were, in 1933, only eleven cases of primary infection' with malaria. This great 'success could never have been achieved, nor could the work have been continued, without adequate sanitary and medical services' (Ilvento, 1934).

In this campaign, drainage and reclamation work were combined with extensive anti-malarial operations (quininisation, systematic treatment, screening and anti-mosquito measures), and special measures to avoid any severe financial stringency among the colonists. Other large schemes of a similar nature have been carried out in the Macarese area of the Tiber Delta and in other parts of Italy. As a result, where previous efforts at reclamation had

failed because of malaria, the disease has been conquered and vanquished, and where fever, starvation and poverty reigned, well-tilled fields are to be found populated by a healthy and happy people (Celli, 1933; Castellani, 1933). The advantages of anti-malarial operations have been so great that the Italian Government consider that the additional outlay, relatively small as compared with the cost of the major engineering works, justifies the result, and is a paying proposition. As shown by the legislation passed, such measures are now fully recognised as an *essential factor* in the success of all large schemes of reclamation in malarious localities in Italy*.

In Spain also, measures for the reclamation of land in malarious areas of this country are now being combined with active operations against the disease (de Buen *et al.*, 1930). Other European countries are taking similar steps.

The gradual reclamation of large tracts of malarious lands in Algeria and other parts of North Africa have proved successful when the engineering and agricultural methods have been combined with anti-malarial ones (Sergent and Sergent, 1921). The large agricultural drainage works have been supplemented by a very vigorous campaign of 'prophylactic' quininisation, and treatment, combined with various other measures directed against mosquito infection. The good results of this work have been described by Sergent and Sergent (1928).

The United States of America was also one of the countries in which the importance of taking steps for the reclamation of fertile but undeveloped malarious tracts was first taken seriously.

Herrick (1903) drew attention to the rich but sparsely populated lands of the Mississippi Delta, the fertility of which was only second to that of the valley of the Nile. He pointed out the advantages which would accrue to the nation if the malaria problem in these areas was tackled successfully.

'Still' says Herrick, 'this land to-day, at least much of it, can be bought at ten to twenty dollars an acre. Thousands of acres in this region are still covered with primeval forest, and the bears and deer still roaming there offer splendid opportunities for the chase'...... 'Why is not this land thickly settled? And why is it not worth two to five hundred dollars an acre? If it produces one to two or more bales of cotton an acre, and it does, it ought to be worth the above-named figures. A bale of cotton to the acre can be produced for thirteen dollars, leaving a net profit of twenty to forty dollars for each bale, or forty to eighty or more dollars for each acre of land cultivated. Moreover this land has been doing that for years, and will do it for years to come, without the addition of one dollar's worth of fertiliser. Land that will produce a net profit of forty to eighty dollars an acre is a splendid investment at one, two, or even three hundred dollars an acre. Yet this land does not sell in the market for anything like so much, because the demand is not sufficient, for white people positively object to living in the delta on account of the malarial fevers and chills. A man said to me not long ago that he would go to the delta that day if he were sure that his own life and the lives of his family would not be shortened thereby. There are thousands exactly like him, and the only reason that these thousands do not go there to buy land and make homes is on account of chills and fevers. But there is a time coming, and that not far distant, when malaria in the delta will not menace the would-be inhabitants. When the time comes it will be the richest and most populous region in the United States'.

A similar opinion is expressed by Howard (1909), who states that 'the loss of this country (the U. S. A.) in the way of the retardation of the development of certain regions, owing to the presence of malaria, is extremely great. Certain territory containing the most fertile soil and capable of the highest

*'By the triple alliance of the doctor, drainage and agriculture, it is possible to thwart the most formidable enemy of our country' (Celli, 1911).

agricultural productiveness is practically abandoned. With the introduction of proper drainage measures and anti-mosquito work of other character, millions of acres of untold capacity could be released from the scourge at a comparatively slight expenditure. These regions in the absence of malaria would have added millions upon millions to the wealth of the country'.

Since that time anti-malarial measures have progressed considerably. 'With the introduction of major agricultural drainage and subsidiary anti-malaria work, thousands of acres have been, and millions will be, released from the scourge at comparatively little cost' (Fuchs, 1922). Hoffman (1928) reports that the number of malarial cases in the Mississippi Delta fell from 64,000 in 1915 to 38,000 in 1924 and the deaths from 656 to 182.

It is recorded by the same author (Hoffman, 1928) that 'enormous areas of fertile land in south-eastern Mississippi have been redeemed and are now flourishing communities where formerly there were but straggling and dilapidated villages. The progress in this respect, which has been made in Mississippi, largely as the result of drainage and the progress of agriculture, is an inspiring one of men's conquest over nature'.

In discussing the 'reclamation of swamp lands and the conquest of the malaria-bearing mosquito' in Missouri, he (Hoffman, 1918) speaks of the large drainage works which have been undertaken to reclaim this unusually fertile region. 'The cost of drainage in Missouri has varied from about $3 to $7 per acre, but to this must be added the cost of clearing the land when timbered, which varies from $12 to $50 per acre. Cleared land, it is said, ranges in price from $50 an acre upwards'.

There are in India many undertakings that are having very similar results to the 'bonification' work of other countries.

The agricultural decline, the increased malarial prevalence, and the depopulation that have occurred in Lower Bengal during the past century, have been graphically described by Bentley (1925), (*vide ante* pp. 228–230; p. 453; pp. 457-458). This author has produced a volume of evidence to show that these calamities are almost certainly due to obstruction to the free passage of water across land tracts of the delta. This was formerly of the nature of 'inundation-irrigation', similar to that in the Nile valley, and the passage of the silt-laden water was not only inimical to the dangerous mosquitoes, but the deposited silt also supplied a very valuable fertiliser to the land. This change in conditions is attributed by Bentley (1925) with very sound reasons, not to natural causes, but to the network of embankments, roads, railways, etc., that has grown up in the last century and has seriously interfered with the natural spread of the beneficial floods*.

Large schemes have been started in several of the affected localities in Bengal, in attempts to restore the free passage of the health- and wealth-giving water over limited areas, with a view to improvement in local agricultural and health conditions. These may be considered as schemes of 'bonification', and are usually combined with certain anti-malarial measures. In how

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*Some of the flood protection and drainage works, which have been constructed with the best intentions, but as they have never achieved that complete agricultural drainage, which is necessary for certain kinds of agricultural bonification, and they have resulted in disasters both to the health and the economic prosperity of the people. Nor would it probably be financially possible or advisable to attempt such a high degree of drainage in most of these large tracts.

far these attempts will prove successful and capable of wider application to the very large tracts affected, remains to be seen. The problem is also complicated by the many other interests who are concerned with the erection of obstructions to the flow of the water of the land. That such efforts, if properly applied, should give rise to great economic benefits, is suggested by the successful results of similar measures in the Tanjore and Rajahmandry districts of Madras, which are instanced by Bentley (1925).

The great network of canals, that has been constructed all over India during the last century, has done much to relieve those conditions of famine and economic stress which were so prevalent previously. As pointed out above (*vide ante* pp. 252–256), economic stress has a marked effect in raising the mortality and morbidity from malaria, so these large works may be considered in the nature of 'bonifications'. At first, these works bring much prosperity to the irrigated localities, but, in the absence of effective drainage systems combined with the provision of irrigation water, unfortunately many areas have become water-logged, thus giving rise to agricultural decline and increased malarial prevalence. Many of the most highly endemic foci of malaria in the Punjab are associated with such water-logging.

The relationship between water-logging, malaria and agricultural decline was pointed out in India by Baker, Dempster and Yule (1847) about 90 years ago. Marchiafava and Bignami (1900), speaking of the history of irrigation in California, say that this 'has made it plain that if irrigation works are not to become producers of malaria, drainage must proceed *pari passu* with irrigation; when this is not done, the water which brings riches brings also malaria'. Watson (1921) also says 'Cromer insists that, in Egypt, the success of irrigation depends no less on the channels for taking off the water than on the irrigation channels for its supply. It is notorious, too, that badly drained irrigated land is not only of less value agriculturally, but is also more malarious than irrigated land, where by means of an efferent system, the water on the land is more fully under control'.

Several workers have commented upon the harmful effects of water-logging in the Punjab Christophers (1924) states that 'in the great Canal colonies, a serious menace is the malaria which is normally induced as the result of irrigation. At first relatively healthy, such areas are liable to an increasing malarial endemicity that, if it does not altogether nullify the good such schemes bring, at least detracts largely from this'. Gill (1930*a*), in discussing the relationship of canal irrigation to malaria, says that 'it is certain that wherever canal irrigation gives rise to water-logging a vicious cycle is set up in which endemic malaria leads to bad health, bad health to economic stress, and economic stress to further privation and sickness, and, finally, as the combined result a high death rate, a low birth rate and emigration, to depopulation of the affected tract'. Fuller details are given by Gill (1927).

Several of the original canals constructed in India were badly aligned, and so interfered with the natural drainage of the country, thus giving rise to water-logging in many instances, not only of local, but, sometimes of wide-spread extent. This led to marked deterioration in agriculture, increased malarial prevalence, poverty and depopulation. One outstanding example of this was the case of the Old Western Jumna Canal, built by the Moghul Emperors and restored under British rule. The appalling state of affairs along the course of this canal was vividly described by Baker, Dempster and Yule (1847), Dempster (1848) and Taylor (1870). This canal was realigned in 1885. As a result there has been an enormous improvement in the health and prosperity of the country through which it runs, and, except for occasional stretches of water-logging, the area has ceased to be one of the plague spots of the Punjab (Macdonald and Majid, 1931). The increase of facilities for treatment has helped in this large and successful measure of bonification.

Although, warned by experience, most of the more recently constructed canals of India have been aligned with a view to the prevention of water-logging, in some instances the absence of an effective drainage system has given rise to this evil with the harmful sequelæ described above by Christophers (1924) and Gill (1930*a*). The results have in these cases been disastrous to the agricultural prosperity of the affected area, apart from their effects upon the health of the local population. The necessity for the provision of proper drainage, etc., in the preparation of canal projects and their execution, is now more widely recognised, and the Water-logging Board of the Punjab (1930) have laid down the principles to be observed. Where these have been adhered to, the disastrous effects observed in the past have been largely mitigated. Unfortunately, in some recent instances, these most important principles have still been neglected and the ill-effects are being already felt, both on the agricultural prosperity and upon the health of the people.

Along canal systems constructed before these principles were fully appreciated, large measures of drainage have now been instituted to improve the agricultural conditions in these areas (*vide* Gill, 1922, 1927; Lal and Shah, 1933), while the promoters of other schemes are beginning to realise the disasters which are following upon the neglect of these principles. In many instances, the enormous losses caused, both in money and lives, have exceeded the initial outlay which would have been needed to prevent these calamities.

In the Punjab and in Sind also, one of the greatest scourges of the population had been the periodical occurrence of large fulminating epidemics of malaria (*vide ante* pp. 243-244). These epidemics were chiefly caused by flooding, and not only has the population been decimated by the disease which followed the floods, but this condition has also been responsible for a very great destruction of crops and property, with resultant economic stress. Extensive engineering measures to limit the occurrence and spread of these floods have been carried out in the Punjab and elsewhere, and have done much to control the frequency, extent and intensity of these awful epidemics*.

The work of Gill (1928), in devising means whereby the areas in the Punjab likely to be affected by these epidemics can be predicted, has helped very much to mitigate the intensity of the mortality and morbidity produced. By these timely warnings, it has been possible to have available before the epidemic curve begins to rise, a suitable medical staff and abundant treatment for the afflicted. These methods for mitigating the effects of flooding and water-logging may be considered as successful measures of major bonification, of which the cost must have been amply repaid by the benefits they confer on both the prosperity and the health of the people.

> 'Drainage, flood protection, improvement in water-logging (in the Punjab) have all been actively prosecuted during the last two decades and have constituted anti-malarial work of a high order, involving improvement of health to such towns as Amritsar and different rural tracts' (Christophers, 1930).

Although the extensive schemes of bonification mentioned above have been of great benefit in alleviating the malarial conditions of the localities affected, many of such works, aimed purely or mainly at agricultural or economic improvement, have not been helpful in reducing the malaria problem. Ilvento

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* Heggs (1935) points out that the most important anti-malarial measure in Iraq is also the prevention of flooding.

(1934) has pointed out the failure or the disastrous results of such schemes in Italy, when not combined with effective measures against this disease. As mentioned already, the large embankments, which were constructed to stop flooding in Bengal, have had a harmful effect on health and agriculture in many instances. The roads and railways of the same province, while constructed to improve social and economic conditions, appear to have had a deleterious effect in many localities, not only by increasing the conditions favourable to the propagation of dangerous mosquitoes, but also by their damage to agriculture (Bentley, 1925).

In some areas, as in the lowlands of Malaya, the clearing of jungle has helped to diminish the malarial prevalence, but in other places, such as the hills of the latter country, in the Andaman Islands, and in Assam, such clearance to extend agriculture, etc., has been the cause of an extremely marked increase in malarial conditions. This was due to the increased facilities for the breeding of a more dangerous type of Anopheline.

It is clear, therefore, that the aid of the expert malariologist is needed in connection with measures of bonification proposed in malarious localities. If such advice be not availed of, the schemes may prove failures, and the cost of remedying the damage done, may greatly exceed that by which it could have been prevented initially.

The great schemes of rural reconstruction which have been launched in most of the provinces of India, should help greatly in the campaign against malaria, by improving the health, the social, the agricultural, the economic and educational conditions of the people. The popular movement initiated by the Anti-Malaria Co-operative Societies of Bengal is of a similar nature, but anti-malarial operations have a much more prominent place than in the official work*. The improvements caused by this movement have been reported from several areas.

From the large amount of evidence available, there is no doubt that in a country like India, where the need for an extension of agriculture into fertile but malarious tracts has become an urgent national problem (Sinton, 1936), it pays to undertake anti-malarial measures to aid in the development of these areas. Indeed, it is an essential to success, and whatever means are taken to reclaim or improve such lands, they should not be started without the provision of appropriate measures to combat the effects of malaria among either the pioneers or the colonists. That such anti-malarial measures are a paying proposition is now recognised in all progressive countries where such schemes of reclamation have been carried out successfully.

(2) SCHEMES FOR WIDESPREAD TREATMENT OF MALARIA.

'The Malaria Commission of the League of Nations, without entering into the vexed problem whether quinine treatment should be counted as a preventive measure or not, consider it to be one of the *primary duties of the Government* (of India) to arrange for adequate medical assistance to the greatest possible number of malaria patients' (Malaria Commission of the League of Nations, 1930).

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* The Annual Reports of these societies give an account of the work done. The Malaria Commission of the League of Nations (1930) have also mentioned the activities seen in some areas. Since the latter time considerable advances have been made.

The more permanent methods of malaria control through mosquito eradication are all relatively slow in showing their beneficial results, while the effects of proper treatment are more rapid in action although much more ephemeral. It is now generally accepted as an axiom that, irrespective of what other measures be adopted for the amelioration or eradication of malaria, treatment of the sick must always be the first step.

While widespread treatment may be depended upon to mitigate the severity of the symptoms, cut short acute paroxysms, save life and increase labour efficiency, it does not in most cases prevent the possibility of continued transmission of the disease by the mosquito, more especially of the severer and most common form of fever in the tropics—malignant tertian malaria.

In areas of relatively low endemicity, treatment with some of the alkaloids of cinchona, such as quinine, if properly applied, usually results in a very great improvement in the sanitary* and economic conditions of the people. The population may eventually reach such a condition of prosperity, that it is able and eager to initiate more effective measures of malaria control directed against the mosquito carrier, and so may decrease the disease permanently to a low level. In areas of high endemicity one cannot hope, with the drugs at present available, to stamp out malaria in large areas, although the severity and other effects of the disease may be markedly mitigated by such means.

The general opinion nowadays is that, *with the knowledge and means at present available*, although proper treatment, better food, and better housing may diminish the severity of the disease, no true *eradication* can be hoped for, unless these are associated with measures, direct or indirect, which reduce the danger from the infected mosquito.

The provision of a widespread treatment 'unquestionably is of real value in localities or sections where the inhabitants are chiefly natives, where an effective public health organisation is wanting, where the density of the population is low, where the climatic conditions are decidedly unfavourable, and where for topographic as well as for economic reasons mosquito eradication and control would be impossible' (Hoffman, 1918). Such conditions are present in most of the malarious portions of the tropical world.

The malaria problem became so acute in Italy at the end of the last century†, that, in 1900, quinine was placed on sale to the public at a minimum price. Shortly after this (1902), quinine became a State monopoly, and 'it is to be noted also that, every fiscal question having been set aside, the net profits of the great State administration went entirely to lessen the causes of malaria' (Celli, 1911)‡. Legislation was also passed, *and enforced,* to make treatment easily available to most of the malarious sick of the country.

*Treatment appears to be less efficacious when the population is poorly nourished and living under bad social conditions (Bentley, 1925; Ilvento, 1934), so with an improvement in economic conditions the treatment becomes more effective.

† A large agricultural bonification scheme (drainage by pumps) had been in action in the Tiber Delta since 1889, but no anti-malarial measures, in the present sense of the word, had been combined with this. This area still remained malarious, and indeed 90 per cent of it was uncultivated for more than thirty years thereafter. 'It was this situation which in the main led to the adoption of State quinine distribution in 1902' (Report of the Rockefeller Foundation for 1934).

‡ *Cf.* Sinton (1935).

The following laws were promulgated:—'That of 23rd December, 1900 (State quinine on sale to the public at a minimum price); that of 2nd November, 1901 (the right of *workers of every kind* to have gratuitously the State quinine *for the treatment* of the fevers from the communal doctors at the expense of the respective employers); that of 22nd June, 1902 (concession at a low price of the State quinine to the communes, charitable institutions, and to those who desire or have to distribute it gratuitously to the workers); that of 25th February, 1903, Article 3 (the right of the *poor* to have quinine with other drugs given them gratuitously by the communes or by charitable institutions); and finally, that of 19th May, 1904 (the right of workers of every kind to have it gratuitously also *for prophylaxis*' (Celli, 1911).

Celli (1911) has tabulated the beneficial results of this far-seeing policy of State treatment upon the mortality in Italy (Table XIII), and of the profits accruing to the State for the extension of their anti-malarial programme.

TABLE XIII.

*State quinine and mortality from malaria (in Italy)**.

CONSUMPTION OF STATE QUININE.		MORTALITY FROM MALARIA.		Net profits of administration of State quinine in lires.
Financial year.	Kilograms sold.	Solar year.	Total deaths.	
..	..	1895	16,461	
..	..	1896	14,017	..
..	..	1897	11,947	..
.	..	1898	11,378	
	..	1899	10,811	..
..	..	1900	15,865	.
..	..	1901	13,861	..
1902–03	2,242	1902	9,908	34,270
1903–04	7,234	1903	8,513	183,039
1904–05	14,071	1904	8,501	183,382
1905–06	18,712	1905	7,838	293,395
1906–07	20,723	1906	4,871	462,290
1907–08	24,351	1907	4,160	700,062
1908–09	23,635	1908	3,463	769,809

* Hoffman (1928) gives later information in which he says that the mortality during the period 1894–1898 was 43·9 per 100,000, as compared with 10 in the period 1909–1913, while James (1930) states that, when this quinine scheme was started in 1900, the mortality was about 500 per million, and was only 61 in 1923.

From this table it can be seen that the annual consumption of quinine increased about 10 times in 7 years, while the malarial mortality progressively diminished four-fifths. In addition to this general fall in mortality, Celli (1911) reports that 'the characteristic periodic recrudescences have no longer presented themselves', and that the fall in mortality was most marked amongst the poorest citizens, 'thus our legislation has begun to reach its high social aim, namely, to break the vicious cycle of poverty and malaria'. This scheme of widespread treatment also had a marked effect in reducing the morbidity and many of the other serious effects of malarial disease.

'One can loudly proclaim that our legislation on State quinine *has not only a scientific, but also a moral and social purpose,* inasmuch as it recognises that malaria is a calamity connected with agricultural work; and it wisely imposes upon the employers the duty of

preventing the damage by giving the preventive quinine gratuitously to the workers, and of compensating them by giving the curative quinine also gratuitously; and to the relatives of employees in public works it assures, besides, the payment of indemnity in cases of death from pernicious fevers' (Celli, 1911). 'The effect of the wide use of quinine on the severity of malaria has been marked and incontrovertible. The death rate from that disease has rapidly decreased. Cases of pernicious malaria are far less frequent now than they were formerly' (Report of the Rockefeller Foundation for 1934).

In many parts of Italy, the peasant has now become so convinced of the value of quinine that he considers it almost equally necessary with his daily bread in the districts where and months when malaria is present*.

The immediate beneficial effects of the State quininisation in Italy were so marked that a unanimous resolution was passed at the Fourteenth International Congress of Hygiene and Demography, urging the extension of this policy.

'The Hygienic Congress urges upon Governments of malarious countries a more active campaign against malaria by means of all the methods proposed by the reporters to the Congress on this subject, and particularly advises:—(*a*) The sale by Government of good cheap quinine on the basis of the Italian law......' (Celli, 1911).

In 1907, encouraged by the results obtained in Italy, the Greek Government passed legislation very similar to that in force in the latter country.

Prior to this time 'considerable abuse took place in connection with the sale of quinine, which is sold in Greece not only by chemists but by grocers. This quinine not only is sometimes of bad quality but is often adulterated with foreign substances, besides which it is far from rarely sold under weight to customers, whilst, to crown all, it is sold at a very high price, so as to render the frequent use of quinine by the poorer classes beyond their means'.† The Government in their bill acquires the right to order and sell any of the salts of quinine recommended by the Royal Sanitary Council. Sales are made by the Chemical Laboratory attached to the Ministry of Finance, by Public Treasuries, post and telegraph offices, educational functionaries, and by authorities chosen by Royal Decree. The State sells quinine at cost price. It is sold retail to the public by chemists, grocers and other merchants, who derive a small profit therefrom. The retail price is fixed by Royal Decree. Importation is not prohibited, but the imports are examined chemically, and must be equal or superior to State quinine'. 'Heavy penalties are prescribed for persons selling State or other quinine above fixed prices, adulterating or selling adulterated quinine smuggled into the kingdom or selling under weight. The law also obliges such communes as are severely scourged by malaria to enter into their budgets an amount destined for the purchase of State quinine, to be distributed gratis to the poor' (Savas 1911).

'Stephanos says that the Greek (like the Italian) peasant values quinine as highly as he does bread. Physicians have noticed that since the use of quinine has become more common, malaria has diminished, not only in extent but in severity' (Jones, 1909).

The Bulgarian Government has also recognised the necessity for having the sale of such an important drug under State control, and has established a State monopoly. The Roumanian and several other European Governments, in whose

* As pointed out above, although the Italian Government pursued this quinine policy with great vigour for 20 years, and obtained an enormous improvement in the health conditions of the people, yet this measure did not succeed in stamping out malaria. This policy is being, and *must be* continued, but the progress produced by this means came to a standstill at a certain level, and no further improvement appeared possible by this method alone. For this reason the Italian Government decided in 1923 that the benefits of this policy must be augmented by measures of a more permanent nature, and have adopted, in addition, those large schemes of 'bonification', combined with anti-malarial measures, which have already been described, as well as an extensive anti-larval campaign.

† Compare these with the present conditions in India (Sinton, 1935).

countries malaria is a menace, have instituted campaigns for widespread treatment of the disease among their poor and their rural populations.

In the French colonisation of the malarious parts of Algeria, the major plank in the campaign has been quininisation, and this is aided by screening and minor anti-larval measures. Sergent and Sergent (1928) have recorded some of the benefits of this work, and report that, in certain communities as the result of an intensive application of this method, the spleen rate has fallen from about 70 per cent to about 5 per cent or less. This work is now combined with larger measures of agricultural bonification*. In Morocco also, such bonification consists of hygienic measures, drainage work and minor anti-larval measures, but is *always* combined with quinine distribution.

Bonne (1924) reports that, in certain communities of the Dutch colonial possessions, malaria almost disappeared after two years of intensive quininisation. 'This does not mean that the population had become normal again; the spleen enlargements for instance were not gone; and the possibility of infection from Anopheles was not taken away, but absence from work through malaria was inconsiderable'. Malaria as an economic problem was no longer of much account.

The eminent German malariologist, Koch, was the great advocate of the use of quininisation in the reduction of malarial prevalence, and Schilling (1911), in reporting upon the prevention of this disease in the German colonies, states that the simplest and cheapest method for this purpose is widespread quininisation. He adds, however, that treatment alone will not always suffice to reduce the morbidity to a degree which is desirable in the politico-economic interest.

In America large commercial companies, such as the United Fruit Co., have found it financially profitable to employ a large staff of experts to deal with the malaria problem among their labour. Deeks (1929), the Chief Medical Officer of this Company, points out that, if the labouring population could be aggregated into villages and camps, anti-mosquito measures could be carried out successfully and economically. As the labour force of the company is widely scattered and undisciplined, this has not been possible in many instances. In these circumstances, the company has had to rely upon treatment, mainly the administration of quinine. Although he notes that this plan is not yet 100 per cent perfect, 'it has, however, resulted in a phenomenal fall in the number of cases requiring hospitalisation, and also in a greatly lessened incidence of malaria in the plantations'. 'There has been a material increase in the earning capacity of all the stabilised labourers'. 'In the Preston Division, Cuba, the cane cut per man per diem in 1925 and 1926 averaged less than 1 ton per day; in 1927, about 1·23 tons; in 1928, 1·39 tons and in 1929 1·61 tons'.

He concludes that 'we are encouraged to believe that malaria can be controlled to such an extent that it ceases to have the serious economic importance which previously prevailed'.

The great results, which have been obtained in the Panama Canal Zone by organised anti-mosquito measures, have already been recorded, and it has been pointed out that this success was almost entirely confined to urban or similar conditions. The difficulty of dealing with scattered communities in this area

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* Algeria is the country of which General Duvivier said in 1841 'Les cemetières sont les seules colonies croissantes que l'Algérie presente', and of which old colonists state 'In Algeria where there is no water one dies of thirst; where there is water one dies of fever' (Sergent and Sergent, 1928).

has been emphasised by Clark (1934). This author thought that much might be accomplished under such conditions by attacking malaria control as a dispensary disease rather than as a hospital disease or as a large sanitary problem. Experimental measures were undertaken in five local villages, having no mosquito control, by taking a monthly blood census and treating with atebrin and plasmoquine, all persons found infected. Clark reports that during four years the blood infection rate fell to about one-fourth of that found in the original survey, but no lower. Usually the same persons were found positive at each survey, and these seldom showed any other evidence of the disease.

The owners of large cotton plantations in the southern states of the U. S. A. are also beginning to realise the value of anti-malarial measures. 'Do you know that malaria caused large losses on certain plantations (in the U. S. A.) in 1925 when cotton was bringing 32 c.? Do you know that these losses could have been prevented for one-fourth their cost?' 'The labor cost is 40–50 per cent of the total cost of production on a plantation. Why study fertilisers, seed, tools, and markets and forget the health of your labour element—without which all other elements are useless?' (Johnson, 1926).

A number of experiments, using different methods of malaria control, were carried out among scattered populations on cotton plantations in the southern states of the U. S. A., to determine the economic feasibility and value of such measures.

Derivaux, Taylor and Haas (1917) undertook a quininisation experiment in a rural area in Chicot County (U. S. A.). The drug was issued to 237 persons, and the reduction in malarial incidence recorded by blood examination was 54·45 per cent. The economic loss due to malaria among a control population of 120 persons averaged \$2·52 per head, as compared with only \$0·06 among the quininised individuals. Rose (1919) also records the beneficial effects of the systematic treatment of malaria carriers in Bolivar County, Miss. (U. S. A.).

On another plantation where quinine was issued twice weekly to all persons in the community, the parasite rate showed a reduction of 64·45 per cent at a cost of 57 cents per head (Rose, 1919). In an area in Mississippi, of about 100 square miles and with a population of about 8,000 individuals employed on cotton plantations, 'it was estimated that from one-third to three-fourths of the people on these plantations have one or more attacks of malaria each year, and that 70 per cent or more of the sickness disability in the community is due to this cause. An intensive course of quinine treatment was given to all persons showing evidence, or having histories, of malarial infection. The degree of malaria control obtained by this means was estimated at 80 per cent (Rose, 1919).

From an analysis of these experiments, Rose (1919) concludes that 'in heavily infected regions, in which the cost of mosquito control would be prohibitive, the amount of malaria may be greatly reduced by resort to screening, to immunising quinine, or to destroying the parasites in the blood of human carriers. The indications would seem, in fact, to justify the hope that by the systematic application of these measures the malaria in a community may be held within reasonable bounds, and that this result may be accomplished within the cost the average community (in the southern states of the U. S. A.) may well afford'.

The Japanese in Formosa have used mass quininisation in their attempts to reduce malaria there. According to Banerjee (1916), the inhabitants were examined and all those showing malarial infection received a course of treatment. 'It is stated that in two districts the mortality from malaria has been reduced from 11·60 to 3·39 per thousand. These results were noted after the system

had been in operation for two years'. Takaki (1911) records that Koch's prophylactic-quinine method was started among the Japanese inhabitants of Formosa in July 1907. In 1906, the number of malaria cases per mille was 5,361, and the deaths 75·14. In 1907, these fell to 1,338 and 10·61 respectively, and in 1908 to 818·2 and 5·23.

Heggs (1935) believes that, in Iraq, a country where a large proportion of the population is scattered, 'the most important anti-malarial measure is the prevention of river floods, and secondly the treatment of existing cases and carriers (of malaria) and the free distribution of quinine'*.

Swellengrebel (1931) insists upon the necessity for an ample supply of quinine for use in the control of malaria among the settler and native populations of South Africa.

'The so-called prophylactic quininisation in the district of Lataba is the most hope-inspiring anti-malarial measure I have seen in Transvaal'...... 'Ample free quinine should certainly be issued to people genuinely unable to pay for it, but wherever payment is possible it should be demanded and the quinine sold as near cost price as possible' (Swellengrebel, 1931).

Watson (1921) gives examples of the benefits of quininisation on some rubber estates in Malaya, but points out that malaria cannot be eradicated by this means, and that the benefits were much less evident in areas of very high endemicity.

On one group of estates where quinine had not been given systematically in 1904, the infection rate among children was 55·5 per cent, while in 1905 after the drug had been given systematically, the rate had fallen to 11·2 per cent. Among adults the percentage of the labour force with malaria among those given quinine was 1·3, as compared with 5·8 among those not receiving this drug. In another estate with a labour force of about 250. where daily quinine was given, the number of coolies unable to work monthly fell from 283 to 18 in 9 months. He reports that with quininisation in October 1906 the coolies were able to work 70·9 per cent of possible days, as compared with only 58 per cent in the same month of the previous year.

India was one of the first countries to realise the need to make provision for a cheap and easily available treatment for her malarious sick. At that time, quinine was a most expensive drug, within the means of but relatively few people. To counteract this, about 70 years ago India started her own plantations to grow cinchona† and to produce a cheaper remedy for the disease. This was a great advance, but it was soon discovered that it was very difficult in such an enormous country as India to make this treatment available to more than a tithe of the population, even through Government dispensaries and hospitals (*vide ante* p. 416).

For this reason, in 1892 was introduced the 'pice packet' system of the sale of quinine through Government agencies, such as Post Offices, etc., which system was changed to the sale of 'treatments' in 1913. Although this method was hopeful it did not solve the problem, because in many parts of the country quinine was not on sale locally, or easily available when wanted, the cost was

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* The Public Health Directorate of Iraq (1935) reports that, although there are only about 3 million inhabitants in that country, a total of 1,500 kilogrammes of quinine was distributed among 277,823 cases during 1934. The number of cases coming for treatment has been more than trebled during the last 10 years, and it is expected that the annual distribution of quinine will rise to 2,000 kilogrammes in the future.

† In recent years other tropical countries, such as East Africa and the Philippine Islands, have started cinchona cultivation, in order to obtain a cheaper treatment for their malarious sick.

frequently more than the patient could afford, and the more ignorant population had not been educated up to the value of the drug. During the great epidemic of 1908, the free issue of quinine was put into practice in the affected areas. In some other provinces free distribution was facilitated by travelling dispensaries, and in the United Provinces and the Punjab, school quininisation experiments were started in a number of localities. These measures must have had a considerable influence in reducing the mortality and morbidity in many of the areas affected.

'There is no doubt that an adequate quinine distribution cannot stop at ensuring the presence of a sufficient quantity of quinine in every village. It will have to see that the people who need it obtain it free of charge or for payment according to circumstances' (Malaria Commission, League of Nations, 1930).

In more recent years, the arrangements for the distribution of treatment, either quinine or cinchona febrifuge, have been considerably extended both through official and non-official agencies—through depôts and sub-depôts of the Public Health Departments, through touring medical officers, through district-board hospitals, through officers of the revenue, police and other non-medical departments, through civilian medical organisations, such as the Red Cross, Anti-Malarial Co-operative Societies, missionaries, etc., through schoolmasters, headmen of villages, local influential people, etc., through schemes of village uplift and rural reconstruction, etc., etc.

It is impossible to make even an approximate estimate of the benefits which this distribution of treatment has had upon the ravages of malaria in India. The incidence of malaria varies markedly from year to year, and, from the undisciplined and poorly educated rural populations, whom one attempts to reach with treatment, it is difficult to obtain any very definite information which would be of scientific value. That the wide use of treatment must have had a very beneficial effect upon the persons who were able to avail themselves of it, cannot be doubted.

Russell and Raja (1935) point out that the population of India has increased 10·6 per cent and the death rate has shown a tendency to fall during the last census decade (1921–1931). They consider that the tendency for the death rate to fall is 'probably due in part to the increased activities of the Public Health Departments, which were re-organised in several provinces after the introduction of the 1919 Reforms'. One part of this sanitary improvement has been a greater and renewed activity in the prosecution of anti-malarial measures, and especially the extension of treatment in rural areas. One is tempted, therefore, to ask whether these measures may not have had some influence in causing the recorded increase in population and the fall in death rate.

The beneficial effects of treatment in those areas of India where epidemics are present have already been mentioned. The provision of adequate treatment is now recognised as an essential and preliminary step in dealing with such calamities once they have occurred*. The fact that in the Punjab it has been found possible to predict the areas where epidemics are likely to occur, has made it possible to have such treatment available before the morbidity has started seriously, and this has done much to mitigate the severity and extent of these outbreaks†.

* The provision of ample treatment has been the factor stressed in dealing with the large epidemics in Russia, Ceylon, South Africa, and other places.

† Swellengrebel (1931) has pointed out that epidemic conditions can probably be predicted in some areas of South Africa, and stresses the importance of this in enabling medical assistance and treatment to be available immediately.

At the construction works on the Mettur Dam in Madras, where medical and sanitary arrangements had been well organised, a malarial epidemic was stopped among the 'tropical aggregation of labour' in Salem camp, by treating the sick for three weeks and also giving quinine widely as a preventive of fever. The spleen rate fell from 70 per cent to 7 per cent (Malaria Commission, League of Nations, 1930).

The school quininisation which was carried out in a number of areas in the United Provinces and the good results obtained have been reported by Graham (1913*c*).

For the last two years, the Government of Bengal have been carrying out an extensive controlled treatment campaign in the rural parts of the Burdwan district, by means of quinine and plasmoquine. Although the final results and conclusions of this work are not available, very beneficial effects on the morbidity, the spleen rate and the fever index are said to be occurring, as compared with neighbouring areas where this treatment is not in force.

Clemesha and Moore (1930) and Clemesha (1931) report very successful results on tea estates in Travancore by means of anti-gametocyte treatment (quinine and plasmoquine), especially of children. Before this was started, the percentage per annum sick from true malaria was never less than about 30 per cent, and 45 per cent was often reached. Within 12 months this rate had fallen to about 10 per cent, and within 2 years it was further reduced, sometimes as low as 2 per cent. This reduction was aided by the use of anti-larval measures also.

Forsyth (1928) reports that, on a group of tea estates in the Tezpur district of Assam, with a population of about 7,600 workers, the malaria attack rate fell with regular quininisation from 268 per cent in 1917 to 121 in 1919. Gupta *et al.* (1933) report on the effects of bi-weekly administration of quinine and plasmoquine in a very malarious village in a forest area of Assam. As a result there was a fall in the number of fever cases, as compared with the untreated population. Among the children the benefits were manifested by a marked fall in the splenic index and in the size of the enlarged spleens*.

These are a few illustrative cases of the benefits which treatment has caused in malarious parts of India under different local conditions.

In spite of this increased provision of facilities for treatment, it is usually accepted that only about one-tenth of the sufferers from malaria in India ever receive any specific treatment for their sickness. Although the difficulty of distribution is one of the obstacles which prevents a wider use of treatment, the cost of drugs like quinine is also a great hindrance†. The Malaria Commission of the League of Nations have stressed the need for the provision of cheap treatment for the poor malaria-stricken populations of the world, as they consider that, in our present state of knowledge, this is the only means by which one can

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* The Annual Reports of the Public Health Commissioner with the Government of India for the last few years have recorded the great benefits which have been obtained in the Army in India by modern methods of malarial treatment. Unfortunately these methods would not be applicable, nor financially possible, for widespread treatment in the rural areas of the tropics. It is also probable that the accomplishment of a permanent cure of infection would not always be advisable in all circumstances (Sinton, 1935*a*; Sinton and Harbhagwan, 1935).

† This question in relation to Indian conditions has been discussed at some length by Sinton (1933) and Sinton (1935).

hope to ameliorate the unfortunate position of these people. By the provision of a free or cheaper remedy than is at present available on the market, a much greater number of persons could be benefited than is possible in the present financial state of both administrations and people*.

Although the Government of India made the pioneer effort of placing treatment at the disposal of her malaria-ridden population, unfortunately the progress in recent years has not been equal to that which has taken place in countries like Italy and Greece, where the sale of quinine and similar cinchona alkaloids has been made a State monopoly, and where the provision of treatment is enforced by legislation. Both the Royal Commission on Agriculture in India (1928) and the Royal Commission on Labour in India (1931) have emphasised the need for the assumption by the Central Government of the control of the cultivation of cinchona, and the sale of the cinchona alkaloids, as a necessary step in the solution of the malaria problem of rural areas in India.

'If India is to embark on any large campaign for fighting malaria, we are convinced that it will first be necessary to reduce considerably the price of quinine in India, and this can only be effected if India is self-supporting in production. To achieve this self-sufficiency, a considerable extension of the present area under cinchona is required'...... 'In view of the all-India importance of the question, it is not one which should be left to local governments, however efficiently they may in the past have carried out their obligations in the matter' (Royal Commission on Agriculture in India, 1928).

'The Malaria Commission of the League of Nations, without entering into the vexed problem whether quinine should be counted as a preventive measure or not, consider it to be one of the *primary duties of the Government* to arrange for the adequate medical assistance for the greatest possible number of malaria patients' (Malaria Commission of the League of Nations, 1930).

Although India has done much to provide treatment for a certain portion of her population, to whom much benefit must have accrued, it is evident that there is an urgent need for a more advanced and wider campaign of treatment. This is more especially the case for rural populations among whom, in our present state of knowledge, there seems at present little hope of eradicating malaria by means of operations directed against the mosquito vector.

'So long as the power to apply anti-larval measures is limited in India, *treatment of malaria remains an all-important point*' (Malaria Commission, League of Nations, 1930).

'Personally I would welcome any measure that is effective, but apparently not even the quinine method has been fully pushed in that country. Experience will, I think, prove to the Government of India that no anti-malaria campaign can be conducted without expense' (Ross, 1911).

The Hon'ble Khan Bahadur Dr. Sir Nasarvanji Choksy, in a resolution which he proposed to the Council of State in 1933, has emphasised the importance of providing ample treatment for the malaria-stricken masses of India.

'Colonel Chopra has estimated the annual economic loss to the country at about Rs. 33 crores. Is it difficult to conceive how greatly India would benefit, if even half of this stupendous loss were to be saved by providing free distribution of quinine, or sold at least at a lower price, or of a suitable cheaper remedy than quinine?'......

'India is on the eve of vast constitutional changes. Those changes will require greater resources'...... 'How are these huge deficits then to be met? The one and only way is to increase the productive capacity of the masses, by freeing them from ill health, disease

*During the last year the Government of India has distributed several thousands of pounds of quinine to each of the provincial Governments, for the purpose of free distribution to the poor. This should help the campaign, but is only a temporary measure. A marked reduction in the present price of malarial remedies is needed to have any more lasting effect (Sinton, 1935).

and death from malaria. India has budgetted this year for Rs. 46·20 crores for its Defence Services. It has, however, been under a preventable economic loss through ill health and poverty of its masses to the extent of Rs. 33 crores annually. The Defence Services are equipped with necessary armaments and appliances to fight the enemy. Why then the sanitarian—the life saver—should be denied his armament of a suitable remedy to protect and preserve the people against malaria that is not an occasional but an ever present foe in our midst?'

'Sir, naught will avail, no constitutional advance will avail, so long as the masses are unable to put forth their full energies in order to furnish their quota of the requisite resources. Let Government spend even Rs. 10 or Rs. 20 lakhs a year to rehabilitate and recondition them and save them by the free or cheap distribution of a remedy for malaria. It will not be too high a price to pay. The immediate results will not take long to show in the ultimate prosperity and contentment of the people and immense benefit to Government revenue'....... 'My sole object in bringing forward this resolution was to attract the notice of the Legislatures with regard to the improvement of the economic condition of the masses and at the same time benefiting the revenues of the country' (Choksy, 1933).

The Annual Conferences of Medical Research Workers at Calcutta have on many occasions passed resolutions emphasising the necessity for immediate steps to make more widely available adequate treatment for the malarious sick of this country, more especially those of rural areas. Such treatment should either be free or within the means of the poorest sufferer. The need for such treatment has also been stressed by the Royal Commission on Agriculture in India (1928).

It is clear from the evidence available, that the treatment of the malarious sick is a paying proposition, both for the humanitarian and the economist, irrespective of what other measures for the control or eradication of this disease be adopted.

'It is evident therefore, that even should it not be possible to suppress malaria entirely, enormous advantages are secured by the supply of quinine to the population, because it is a protection against sickness and consequent inability to work, and a safeguard against financial loss'....... 'Considered from a financial standpoint therefore, the systematic administration of quinine is a valuable economic measure and may be regarded as an insurance premium which no large undertaking or company in the tropics should omit to pay' (Bureau for Increasing the Use of Quinine, 1927).

It is recognised that by this means it can seldom or never be hoped to eradicate the disease, except when the treatment is augmented by other measures, either direct or indirect. While the more radical methods aimed at the destruction of the insect vector are preferable, there are few places where such measures can, for financial reasons, be applied among the scattered rural populations of the tropics*.

'The data here given show that the fight against malaria must not be based exclusively on sanitation work only; nor exclusively on the distribution of quinine. Only from a combination of both methods can the desired result be expected. Which of the two shall be preponderant is entirely dependent on local conditions; but it may be said that for the present for large areas with a dominant rural population the distribution of quinine, combined with small anti-larval measures, is the most economical way in regard to expenses, while, at the same time, it gives direct result' (Van der Spek, 1925).

The Malaria Commission of the League of Nations after a very careful study of the rural malaria problem, both in Europe and many other countries, came to the conclusion that, in our present state of knowledge, the only immediate hope of ameliorating the lot of the bulk of the malaria-stricken

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* In the parts of Italy where most of the agricultural population largely reside in towns 'in every instance it proved less expensive to abolish malaria than to treat it with quinine' (Report of the Rockefeller Foundation for 1932).

populations of rural areas of the tropics, was to make freely and widely available a cheap treatment*.

By making treatment available to even the poorest sufferer, and teaching him to appreciate its value, we may hope to (i) decrease the risk of a fatal result from malaria, (ii) diminish the intensity and duration of attacks of the disease, (iii) curtail the period of physical and mental disability caused by the disease, and so (iv) the period of labour inefficiency. When these results have been attained, the social, intellectual and economic conditions of the population will be raised. The people will be then in a better position, both to realise the advantages of more effectual methods for the control of the disease and to put these into practice.

Apart from the manifest duty of every community or Government, from the humanitarian standpoint alone, to provide adequate treatment for its malarious sick, it is an essential step and a paying proposition in relation to the social and economic progress of the people.

(3) MISCELLANEOUS ANTI-MALARIAL MEASURES IN RURAL AREAS.

(i) Protection against mosquitoes.

The benefits of anti-larval measures, when these can be properly applied, and of treatment, have been dealt with already. The appropriate siteing of habitations in malarious areas is also one of the well-recognised principles of protection against this disease, but is unfortunately often neglected. Christophers (1925a) has given a case in point, and Watson (1921) has shown the benefits which may arise through removal of habitations to a more healthy area. The results amply compensated for the cost.

The destruction of adult mosquitoes in houses was one of the early anti-malarial measures carried out in the Panama Canal Zone (Chamberlain, 1929), and the value of this has been stressed by James in relation to European conditions. Swellengrebel (1931) remarks on its value in the homes of settlers in malarious localities in South Africa, more especially, if these be screened, and Paterson (1935) recommends its employment in East Africa. In both cases the use of insecticides is advised for this purpose.

The screening of houses was one of the original anti-malarial measures undertaken, with beneficial results, by the Italian Government to protect scattered railway officials and custom-house officers in malarious zones (*vide* Table X). Celli (1911) reports that the mean percentage of cases of malaria among the railway staff diminished from 69 92 to 15·79, and the mean days of illness from 5·48 to 3·17, owing to the gradual introduction of mechanical, and later added quinine, prophylaxis. Similarly among custom-house officers, the percentage of malaria fell from 65·30 to 4·83. Laveran (1907) states that, after the Italian law of 2nd November, 1901, made mechanical protection obligatory for all government employees and workmen, very beneficial results were obtained. Among 5,165 persons, more or less completely protected, there were 20 per cent of relapses and 3·3 per cent of fresh infections; among 4,363 persons completely protected, the figures were 21 per cent and 1·9 per cent respectively, while among 802 individuals incompletely protected (bed-rooms only screened) the fresh infections were 10·9 per cent. On the other hand, among populations in the same localities, who were not protected by

* This question has been discussed by Sinton (1933, 1935)

screening, 40 to 60 per cent developed malaria, and in one instance 90 per cent. Laveran (1907) considers that even better results can be obtained when screening is combined with quininisation*.

Rose (1919) and Ferrell (1920) say that in a group of plantations in Arkansas, a small screening experiment, which cost about $1·75 per head per annum, resulted in a reduction by about 70 per cent of the ague rate.

Swellengrebel (1931) records that, on certain unscreened farms in South Africa, the spleen rate was 88 per cent among 26 children, and 58 per cent among 31 adults. On the other hand, these figures were 44 and 10 respectively on screened farms, even although the screening was far from perfect.

'Measures of personal prophylaxis (quinine; screening) have been carried out with such promising results, in some places at least, that no objections to their use could deter me from recommending them, once my investigation had taught me that the results were real and measurable ones' (Swellengrebel, 1931).

There is no doubt that when screening is properly applied and properly used, a very great protection against malarial infection is given. Unfortunately, to be properly effective, it is necessary that the houses should be suitably constructed for the installation of screens, and also that the inhabitants of screened houses should be educated sufficiently to use the protection provided, in a proper manner. In most rural areas of the tropics, the houses of the poor are quite unsuitable for the installation of screens, the cost is high, and the inhabitants are seldom sufficiently educated to use them properly.

In certain rural areas of the United States, screening has been employed in a large number of houses, the construction of which was not ideally suited to their use, nevertheless it was found that even poor screening was better than none. Similar conclusions have been arrived at by other workers in other countries. Boyd (1926) investigated the efficacy of screening under different conditions, and showed the value of this method (Table XIV).

TABLE XIV.

The mosquito protection afforded by screened dwellings and the relation to the degree of protection.

	Number of houses.	Population.	Cases of malaria.	Rates per 100 residents	Cases per house.
1. Tight house, good screens	174	846	43	5·1	0·24
2. Tight house, poor screens	146	812	95	11·7	0·65
3. Tight house, no screens	43	246	47	19·1	0·92
4. Open house, screened	88	408	52	12·7	0·59
5. Open house, no screens	53	258	61	23·5	1·12
TOTAL ..	504	2,570	298	11·6	0·59

Deeks (1926) reports that in Dr. Clark's surveys in Honduras, it was found that, of 2,607 native (partially-immune) inhabitants living in unscreened quarters, 29·1 per cent showed malarial infection, while among 135 non-immune foreigners living in screened buildings, the rate was only 6·6 per cent.

*The good results obtained by screening military barracks have been mentioned previously (Table XI).

As protection from the bites of infected mosquitoes is a proven method of great value against malaria, the use of the mosquito net is to be advocated as a method of protection for scattered populations, apart from any other means employed. Russell and Nono (1934), after much investigation of the problem of rural malaria in the Philippine Islands, came to the following conclusion—'It seems likely that in this country the most important weapon against malaria is the mosquito net. There is practically nothing which the average citizen can do to combat the disease except to use a protecting net at night'. Paterson (1935) speaks of its value in East Africa.

In the mosquito-infected areas round Bangkok, every person, no matter how poor, uses a mosquito net. In India formerly the cost of a net was often beyond the means of the average rural inhabitant, nor did he know how to use one properly. During the last few years in Assam and the Punjab, a cheap type of net has been placed on the market, and an extensive campaign of education in its uses and value is being carried out. This should do much to help the malaria problem. Russell and Nono (1934) have taken similar steps in the Philippine Islands. The effects of these campaigns should prove to the rural inhabitant that it is a paying proposition to purchase and use a net. It is now universally admitted that the proper use of the mosquito net is the most valuable single measure of personal prophylaxis that can be taken by the individual to prevent infection in malarious localities. Covell *et al.* (1935) also emphasise the need for the popularising of mosquito nets in the malarious areas of Sind, India.

(*ii*) *Education, etc.*

'Public health (in India) has been transferred to self-government. Consequently, the people, who elect their representatives, can provide public health or not as they like. It seems that, in this way, a heavy responsibility has been laid on the shoulders of the people; it has to be faced, and it can be faced in one way only; rendering the task easier of accomplishment by educating the young receptive minds in the schools. *The future of public health lies in the hands of the younger generation*' (Malaria Commission, League of Nations, 1930).

In an earlier part of this paper (*vide ante* pp. 423–426), the marked obstacles which malaria places in the way of the education of the younger generation in localities where this disease prevails have been emphasised. Physically a sick child is unable to attend school regularly, and mentally he is not in a condition to take full advantage of the instruction provided for him. The relatively low economic and social status of the population of malarious areas, often makes it imperative that the children should be employed, at as early an age as possible, upon duties which will give a more immediate financial return or its equivalent, to the detriment of their education. In addition, the parents are usually not of a sufficiently high grade of intelligence to appreciate the great benefits which proper education will confer at a later date, even if it were financially possible for them to take advantage of the facilities offered. Unless the health of the children is improved, much of the money provided for education in malarious areas will be wasted.

If India or any other malarious country is to attain the prosperity, economic, social and intellectual, to which they aspire, it is essential that this burden should be removed from the younger generation to enable them to take full advantage of their opportunities. It is obvious, therefore, that any

measures directed towards the eradication or amelioration of malaria would be repaid by the greater benefits derived from the money spent on education.

'We are living in the twentieth century, when progressive races of men are striving for the general improvement of mankind, which means better health, morals and industrial progress for all by education. Good morals and industrial progress depend upon good health, for the most difficult people in the world to uplift are the unhealthy, and much of the money spent on their education is wasted unless their health is first improved' (Nicholls, 1924).

With the benefits which follow upon the amelioration of malaria among the rural population, they will begin to lose that apathy, that ignorance, that prejudice, and that lack of public spirit, which exists among a malaria-stricken population. The younger generation will grow up with an aroused public conscience and an understanding of the loss of health, wealth and life which malaria is causing. They will gradually break down that apathy and lack of co-operation which has been such a stumbling-block to sanitary improvements among all ignorant and diseased populations.

When the rural population begin to develop a 'sanitary conscience', their economic and social status will improve. They will begin to realise that disease is not an evil which cannot be prevented, or at least diminished. They will no longer look upon it as inevitable, to be borne without complaint and considered as a visitation of Providence. They will then begin to demand of the Government, who are their trustees, that more active measures be taken to mitigate the ravages caused by diseases such as malaria.

By treatment and other appropriate anti-malarial measures, it is possible to improve the health, and the social, intellectual and economic status of these people. When this has been done they will then be in a much better position to appreciate the importance of, and to take a more active part in, measures for the eradication of the disease.

'In many instances, indeed, malaria is the paramount condition which stands in the way of health and progress and which must be cleared away before these communities, industries and people can be put on an equal footing with those not menaced by the disease' (Stinson, quoted by Hoffman, 1928).

'In general, I think the statement is true that a seriously malaria-ridden population is incapable, unaided, of maintaining a well-balanced health program. The obvious indication is to get rid of malaria first, put the community on a par with others which fortunately do not suffer this handicap, and then proceed with normal development of health and of economic and cultural development' (Cumming, 1927).

The beneficial effects of education in facilitating all measures for the control or eradication of malaria have been recognised in most progressive countries. In Italy, Spain and many other European countries the children in schools, more especially those in rural and malarious areas, receive special instruction about the causation and prevention of this disease*. The importance of such instruction, as an essential step in malaria eradication, is now recognised in many tropical countries [*cf.* Swellengrebel (1931) in South Africa; Russell (1933) in the Philippine Islands, etc.].

The need of such education in India has been emphasised by Christophers (1930). He points out that the rural population of this country is 'lacking in public spirit, with a tremendous amount of ignorance and apathy, having no "health conscience" or even any adequate appreciation of what is in the mind

* In Italy in the Roman Campagna, school teachers are specially trained in this branch of rural hygiene, and hold special classes for school children. At the same time, a distribution of treatment is made through the scholars.

of the sanitarian who may attempt to rouse their enthusiasm in such cause. Education in hygiene, not malaria prevention, is the only outlook one can see at present for this vast problem of rural sanitation. Schools, fairs, travelling dispensaries, district health officers, all the elements that go to education and propaganda, malaria exhibits, railway publicity trains, a hundred and one methods, but not yet anti-larval operations'.

For some years such an educational campaign in rural hygiene has been in progress in India, and is being steadily expanded in many provinces, by both official and non-official agencies. This should do much to educate the people, and more especially the younger generation, to an appreciation of the urgent necessity of measures against malaria. The routine quininisation of malarious children, which has been started in the schools in many localities, should also do much to help in raising the educational and intellectual standard of the children in those places, as it has done in other parts of the world.

It is impossible to evaluate the benefits of such a campaign of rural sanitation in rupees, annas and pies, but its indirect effects in raising the economic, social and intellectual status of the people, must be enormous. Such an uplift will be reflected in the rise in prosperity of the people, and so in the financial position of the country.

No campaign against malaria can hope to be completely successful unless there is genuine co-operation between all Governments, administrations and departments, in the efforts to eradicate or ameliorate the scourge.

'Every authority on malaria eradication agrees that the practical solution of the question is primarily one of active and intelligent co-operation on the part of the government and the many-varied associated activities of the general public. Regardless of the encouraging evidence of malaria reduction in many sections of the world, the anticipated progress based upon the clear recognition of the causative factor in malaria dissemination had not been made'....... 'If more rapid progress is to be made within a measurable period of time, much more is required than has heretofore been the case. The movement for malaria eradication will necessarily gain force in proportion as the economic aspects of the problem are more clearly realised and the achievements in particular localities are brought intelligently to public attention' (Hoffman, 1928).

This need for co-operation has been stressed by workers in many parts of the world. To achieve this result requires not only the enlightenment of the ignorant masses, but also of the more educated population, both official and non-official.

The Governor of the Punjab, His Excellency Sir Herbert Emerson, in an address delivered in 1935 at the opening of the Punjab Engineering Congress, points out the tendency of Government Departments to look upon problems from the aspect of how they affect the budgets of their own departments and *not* that of the province as a whole. He points out the necessity of co-operation between different departments in the interests of the finances of the Government of which they form parts, and not of their own departments only. He wished to impress upon all officials, etc., the drastic steps which should be taken against all who fail to take part in such co-operation for the common good of the province.

This lack of co-operation was experienced by Gorgas in the early days of the construction of the Panama Canal, and threatened to cause a repetition of the disaster experienced by the French Company there. The late President Roosevelt realised the paramount importance of such co-operation in health measures by all interests engaged on the work, and took drastic steps to ensure this. The successful results of such measures have been mentioned above. Similarly in Italy the recent brilliant bonification schemes owed their success to the co-operation which was enforced in connection with these undertakings.

Where there is lack of co-operation from any source, the necessity for appropriate legislation and orders, with strict measures to enforce them, has been recognised in many parts of the world. Until education and co-operation have reached a higher level than at present, the passing of such legislation and orders, *and their enforcement*, is a necessity in most malarious areas.

The unsuccessful, or poor, results which have been reported in many parts of the world, when properly planned anti-malarial measures have been recommended, especially for urban areas, are, alas, too often due to the apathy, to the neglect, to the absence of co-operation, and even to the active opposition of either the non-official, or the official population, or of both.

After their tour in India, the Malaria Commission of the League of Nations (1930) report 'although we adhere to our previous statement that rural malaria is the most important problem, we look upon it as a defect that the simple clear-cut conditions of urban malaria have not been controlled'. In some instances, the health of the people appears to have been sacrificed in the interests of political, religious or departmental ends. This has been specially noted by the Malaria Commission of the League of Nations (1930), by the Royal Commission on Labour in India (1931), and by Covell (1928, 1934).

'We need not insist on a history of all the attempts to carry out an efficient malaria control. Up to the present they have failed, not through want of sufficient knowledge or of means to carry them out, but through a deplorable lack of co-operation between the various authorities, through religious objections which must be respected in so far as they are sincere and not a weapon in the hands of politicians, and through agitation in certain sections of the Press, which would appear not to be aware of their great responsibilities'.......
'If the people of the local boards of the city of Bombay could set aside personal feelings, political animosities and religious scruples, and could combine to drive the enemy from a position that has only been tenable through mutual discord in the attacking force, we believe a moral impetus of no mean value will be given to the rest of India' (Malaria Commission, League of Nations, 1930).*

'We have found that only too often action on health matters ends with the holding of an investigation and the writing of a report, little effort being made subsequently to carry out even the simplest of its recommendations' (Royal Commission of Labour in India, 1931).†

The good results which have since been achieved in Bombay were only obtained after a strenuous campaign by the Malaria Department, and by attempts to enforce the legislation passed to deal with the menace of wells. Much still remains to be done.

This apathy and opposition has been felt in many more enlightened countries than India, and to overcome this, very drastic measures have often been required.

'While public sentiment is still at sea, while our legislators, forgetting Beaconfield's axiom that "the public health is the foundation on which reposes the happiness of the people and the power of the country", and ignoring his high challenge that "care of public health is the first duty of a statesman", allow themselves to be duped or bribed into the support of movements against the public weal that would disgrace the dark ages, how can we hold up our heads in a scientific and cultured age?' (Wellman, 1913).

'As has been well said by the late William Edward Hartpole Lecky—"How different would have been the condition of the world and how far greater would have been the popularity of a strong monarchy if at the time when such a form of government generally

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* The apathy at the City of Vizagapatam is also instanced by the Malaria Commission of the League of Nations (1930).

† A similar statement has been made by a reviewer in the *Tropical Diseases Bulletin* (1935) in respect of New Delhi.

prevailed, rulers had had the intelligence to put before them the improvement of the health of the people and the prolongation of the lives of their subjects as the main object of their policy rather than military glory or the acquisition of territory or mere ostentatious and selfish display " ' (Hoffman, 1928). ' Even the most stately grandeur is ineffective in subduing disease ' (Celli, 1933).

' Even now malaria mosquitoes can be seen swarming in fairly thickly populated places simply because the inhabitants do not take the trouble to keep them down. It is generally the fault of municipal authorities. I certainly think that not enough discipline is exerted by British and European Governments to make local bodies in the tropics do their duty in this respect ' (Mégroz, 1931).

While it has been shown that anti-malarial operations are a paying proposition in urban areas, the cost of these has, in many instances, been markedly increased by the absence of co-operation and even by active opposition to the measures, for various reasons.

This apathy and lack of co-operation has in many instances resulted not only in a failure of schemes to diminish malaria, but in some instances has resulted in an increase of the disease with its attendant evils.

Minor instances of man-made malaria are only too evident in most malarious countries. Examples of the effects of large engineering works in increasing malarial incidence in rural areas have already been cited. In the construction of such works, the engineer naturally tries to complete the project as cheaply as possible, consistent with technical efficiency, and often takes no heed of, or does not realise, the disastrous effects to health and prosperity which may follow from his operations. As remarked by Sir Malcolm Watson, ' engineering which leaves a trail of malaria behind it is bad engineering '. The type of economy which gives rise to man-made malaria is a false saving. The cost of the damage done, and the expenditure which has to be incurred at a later date to ameliorate or remedy the harm caused, are usually very much greater than the initial outlay needed to prevent these. The conditions, produced by neglect of this principle of co-operation between departments for the common advantage of the finances of their Governments, have caused in India and elsewhere the loss of very many thousands of lives and crores of rupees, apart from the suffering of the population and the retardation of social and economic progress.

It is evident, therefore, that the education of legislators and of the official population in the need for co-operation in anti-malarial measures would result in an enormous financial saving. Where such co-operation has been enforced in other countries, the effects have shown that such a step is a very paying proposition.

(c) SUMMARY.

From the evidence available, it has been shown that the eradication of malaria by anti-mosquito measures, with our present knowledge and with the means at our disposal, is seldom financially possible in scattered populations, save under very exceptional conditions. There are, however, proven methods by which it is possible to *ameliorate* the unfortunate conditions of malaria-stricken populations, and so improve their economic, sanitary and social status.

Large schemes of agricultural ' bonification ', rural reconstruction, and village uplift are aids in the solution of the problem of malaria among rural and scattered populations, but, in order to obtain the full financial and economic benefits from such measures, it is *essential* that they be combined in all cases with an active campaign against the disease. It has been proved,

over and over again, that such a campaign is a paying proposition, and that the benefits produced, directly and indirectly, are manifold greater than the cost of such measures.

Apart from such expensive schemes, it is financially possible to improve the condition of rural populations by the provision of treatment for malaria, and by means of protection against infection (screening and nets).

In India, it is the rural population which forms the bulk of the people, and upon whose activities depends the major portion of the wealth of the country. It is evident, therefore, that any measures which improve the condition of these people will react upon the prosperity of India and so be a paying proposition.

Large amounts of the money spent upon education are wasted because malaria-stricken children are incapable, either physically, or mentally or both, of taking full advantage of the facilities afforded for instruction. This retarded development is a serious obstacle to the social and economic progress of the people, and so to prosperity and increased national wealth.

The lack of appreciation of the value of sanitary measures among both the illiterate and the educated populations, has added much to the cost of all measures aimed at improvement.

The absence of close co-operation between all departments, which have, as their object, the increased prosperity and well-being of the people and the State, has in many instances been responsible for a vast wastage in lives, health and money. And not only this, such errors of omission and commission, have given rise to a diminished return on the capital invested, and also to heavy expenditure to repair the damage which could have largely been avoided at a much smaller initial outlay.

From the evidence given, it is perfectly clear that the cost of all appropriate measures aimed at the prevention of malaria, or the amelioration of this condition among scattered populations, more especially agricultural ones, would be amply repaid by the increased social, intellectual and economic benefits produced.

(III) DISCUSSION.

'Unhappily, *eradication is not* at present a practical proposition; *reduction of malaria is*, and that reduction is an imperial and an economic problem of the first importance' (Hehir, 1927).

'I think it is no exaggeration to state that so far as the material side of the question is concerned, the benefit derived annually from the anti-malaria campaign (in Italy) is sevenfold the value of the money expended. As regards the moral aspect, any comparison is out of the question' (Grassi).

'It, therefore, requires no extended argument to emphasize the great economic value of mosquito extermination and malaria eradication as a basis for the economic prosperity of the regions affected. The progress which is being made in this direction is one of the greatest movements of modern medicine and bids fair in the course of time to make enormous regions in the tropics and sub-tropics available for colonization and successful commercial development' (Hoffman, 1928).

'But malarial fever is important, not only because of the misery which it inflicts on mankind, but because of the serious opposition which it has always given to the march of civilisation in the tropics. It is therefore the principal and gigantic ally of barbarism. No wild deserts, no savage races, no geographical difficulties have proved so inimical to civilisation as this disease' (Ross, 1905).

'It is necessarily a political disease—one which affects the welfare of whole countries; and the prevention of it (malaria) should therefore be an important branch of public administration'....... 'The prevention of malaria on a large scale is a great economical as well as a great humanitarian undertaking'....... 'For the State as for the individual, health

is the first postulate of prosperity. And prosperity should be the first object of scientific government' (Ross, 1911).

'Mankind has hitherto not effected more than one-tenth of the improvement of health which it might have effected already if it had put its heart into the business' (of malaria prevention) (Ross, 1914).

'It can be said in truth that in the tropics where there is malaria, its control is the only sure foundation on which tropical hygiene can be built' (Watson, 1933).

'The general conclusion is that wherever malaria exists it is important, and even imperative, to take action of some sort to control it' (Morin, 1935*a*).

The mass of evidence cited, indicated quite clearly that, in the case of urban population, or collections of persons the protection of whose health is essential for special reasons, properly executed anti-malarial measures are financially a paying proposition, and the money spent is very often an investment which pays high dividends. This fact has been proved, and is acknowledged in most of the progressive countries where this problem has been tackled systematically.

With such settled collections of people, it is usually more economical to spend money on permanent measures for mosquito eradication rather than on those of a more temporary nature.

In the case of scattered and rural populations, except in very special conditions, it is seldom possible, financially or economically, in our present state of knowledge and with the means at our disposal, to initiate for public health reasons only, the more permanent measures suitable for urban populations.

Too often expenditure on anti-malarial measures is provided for the benefit of urban populations to the neglect of rural ones. This is because the former, being better educated and more influential, raise a great outcry if their health or economic conditions be seriously affected by the disease. The 'inarticulate masses' of rural areas seldom make any violent protests about their unhappy condition, because of their state of apathy and ignorance, which is enhanced by malaria (*vide ante* pp. 147–151).

While the beneficial results of anti-malarial operations in urban areas are usually apparent relatively quickly, and are more easily appreciated by the lay mind, this is seldom the case in rural localities. In the latter places the benefits, which are marked, are mainly caused indirectly, and the economic results are so gradually developed in most instances that they attract comparatively little attention. For these reasons, Governments and other administrations are chary of spending large sums of money for schemes from which they are unable to demonstrate more immediate results. While anti-malarial operations in such areas may be forced upon them by humanitarian reasons, they are seldom pursued with the same enthusiasm, thoroughness and persistence as those schemes from which a more obvious financial result can be expected.

While individual enterprise and commercial undertakings are *relatively* quick in taking advantage of the information provided by the progress of science, governments and similar administrations based on democratic principles, are notoriously slow and conservative in this respect. They require that immediate results may be guaranteed for the expenditure involved.

'Governments, in general, seem to fight shy of embarking on new sanitary schemes, which at first sight appear to be of an experimental nature, and which may, ultimately, fail to bring about the expected millenium for the betterment of the general standard of public health of any country. They are often obsessed with the idea that no new adventure is worth the

expenditure, unless it brings back quick returns by way of total abolition of disease or diseases' (Rao, 1929*a*).

'The Government (of Egypt in relation to irrigation)', says Sir William Willcocks, 'does not consider only the direct gains from taxation (*e.g.*, the land tax), it considers the increased transport on its railways, the increased import of necessaries, the increased use of duty-paying luxuries like tobacco, the diminished losses of revenue in years of scarcity and the improved well-being of its population. India, as a rule, does exactly the opposite. With rare exceptions, it calculates the expenditure and revenue on its projects on commercial lines, just as though it had only direct taxes to deal with; and on this account rejects project after project in the tracts where they are most needed and carries them out where they pay best whether they are needed or not' (Bentley, 1925).

One can often make an estimate of the financial benefits which anti-malarial operations confer upon towns and special collections of people. This is, however, seldom possible in the case of scattered or rural populations. Here the financial results are much more indirect and depend upon the general increase in prosperity caused by the rise in the social and economic levels of the people. They are none the less important on that account.

'This is but one aspect of the question, the actual cost of the disease; there are other matters, such as the gain from improved sanitation, from enhanced earning power of the population, from the lengthened years of productive life, and these are inestimable' (Balfour and Scott, 1924).

It must be remembered that 'measurable human progress consists not only in the accumulation of material wealth, however vast, in inventions, however marvellous, or in intellectual attainments, however astonishing, but as much, if not more, in the lengthening of human life, in the elimination of needless disease, the prevention of useless accidents, and in the consequential increase in the real human happiness, obtained through the realisation of a distinctly higher level of civilisation' (Hoffman, 1928).

While the eradication of malaria by anti-mosquito measures appears at present the ideal to be aimed at, such steps should always be combined with the provision of adequate treatment for the sufferers. Such treatment lowers morbidity and mortality, and raises labour efficiency. It is very difficult to evaluate these benefits in terms of money, but, from the standpoint of the humanitarian and the social economist, they are very great.

It has been shown that the degree of success of all schemes of bonification, rural reconstruction, village uplift, etc., in malarious localities, is very largely influenced by the prevalence of this disease, and the amount of control which is obtained.

The initiation of more active measures against the malarial prevalence among the agricultural population is specially indicated in the case of India. As remarked by Celli (1933), 'the unhappy vicissitudes of political events may suspend but cannot destroy agricultural life: just as the most stately grandeur is ineffective in subduing disease'. There is very good reason to suppose that the decline of the splendours of some of the most famous civilisations of the past has been caused or at least accelerated by malaria. While political events cannot destroy agricultural life, malaria is the only disease which can and does (*vide ante* pp. 456–460), so the importance of this problem to India cannot be over-estimated.

Few will dispute the statements that 'compared with agriculture, the other industries of India, though they play a useful part in the economic life of the country, are of minor importance. Agriculture is, and always will be the great field of industrial activity, for upon it the welfare and prosperity of the masses

of India depend' (Hehir, 1927). Sinton (1936) has also pointed out the obstacle which malaria is placing in the way of the fullest development of the natural resources of the country, and so of the solution of the urgent problems of the provision of employment for the rapidly increasing masses and of an adequate food supply for these.

It is evident, therefore, that any appropriate measures to improve the health, and so the economic and other conditions of the agricultural population —the backbone of the nation—must prove paying propositions. The time has arrived when this has become an economic necessity, and one which deserves the most urgent consideration of all Governments and administrations.

Two great Royal Commissions which have visited India in recent years, namely that on Agriculture and that on Labour, have both stressed the widespread and harmful influence which malaria has upon the subjects investigated. Many other eminent authorities have emphasised the importance of malaria to India, and the very urgent need for more active and extended measures to combat the ravages of this disease.

'Whether from the point of view of enhanced mortality, sickness and individual suffering, or from the effect of preventing natural increase and sapping the vitality of populations, or the paralysing effect on industry and exploitation of mineral and other natural wealth of the country, or in the direct loss of Government in a variety of ways, malaria is universally recognised as the most important sanitary problem with which India has to cope' (Christophers, 1926).

'All I can say is that the tribute paid to disease in a country like India is one of importance economically, even politically, and one that has many financial and commercial aspects. It however transcends this in being of importance to the welfare of 360 million human beings, which by their tacit acceptance of such calls as may be made upon them, signify their belief that they are being governed to the best ability of those responsible for such government. The important matter therefore seems to be that proper and enlightened views should be held by Government as to the steps to be taken to justify this trust, in so far as the prevention and amelioration of disease is concerned' (Christophers, 1924).

'It is true, of course, that malaria in India is absolutely of the very first order of practical importance, and that any measures and means of the Government in the direction of malaria prevention are certain to prove of enormous value to the people of India'...... 'With ever-increasing economic pressure the necessity for the elimination of the ill-health-producing conditions has become a governmental problem of the first order of importance, and in no special field of preventive medicine have the actual results of governmental interference and control been more satisfactory and conclusive as in the prevention of malaria'...... 'Nowhere in the world is the problem of greater medical and economic importance than in India' (Hoffman, 1928).

'The prevention of malaria is probably one of the most important economic and industrial problems in India. From the vastness of the subject and the numerous complex factors associated with the endemiology of malaria in this country, the difficulties to be encountered in reducing the disease are formidable. Nevertheless, it may with confidence be said that the eradication of malaria in India would, in a single generation, convert that country into one of the most prosperous in the world'...... 'In the civil population the many millions of labourers constantly unfit deserve the grave consideration of all statesmen who control and administer public health measures in India' (Hehir, 1927).

'During our tours we could not fail to be impressed with the tremendous importance of malaria in connection with the health of the industrial worker, and in our opinion, it would pay both Government and employers to initiate a much more active policy of prevention than has hitherto been undertaken' (Royal Commission on Labour in India, 1931).

'We cannot help feeling that malaria control in India should be very much more actively prosecuted as a general duty by the public health departments, and that the control of rural malaria should be taken up more seriously' (Malaria Commission, League of Nations, 1930).

In August 1927, Lieut.-Colonel Russell, the Director of Public Health, Madras Presidency, stated that 'considering the handicaps which malaria places on any population, retarding their social and economic advancement in the world of nations, and considering

how seriously it affects the general prosperity and development of the country, the prevention of malaria is a matter of the first rate importance, which no Government in India can afford to ignore' (Rao, 1929*a*).

In a speech proposing a resolution in the Imperial Council of India, *re* the prevention of malaria, the Hon'ble Surendra Nath Banerjee, after pointing out the havoc caused by this disease and the urgent necessity for more active remedial measures, says—' And, after all, my Lord, malaria is a preventable disease. It is not one of those scourges from which there is no escape, which we must submit to with all the fortitude and the patience we can muster'....... 'A Government that will give us the inestimable boon of health will raise for itself a monument more lasting than brass in the gratitude, the affections and the contentment of a happy and prosperous people' (Banerjee, 1916).

The evidence given above shows that the prevention or amelioration of malaria is a paying proposition from the economic standpoint, both directly and indirectly. One must also consider the subject from the point of view of the humanitarian.

It has been shown that *at least* one million persons die each year in India from the direct effects of malaria, and probably another million succumb to its indirect action, and that *at least* 100 million people suffer from this disease annually. This is a state of affairs which requires the most serious, the most urgent and continued attention of the Government, apart from any financial or other economic considerations. While malaria remains the 'Captain of the men of death, sickness and suffering' in India, it is evident that an immediate, active, vigorous and continuous warfare must be declared against it. 'The lives of men, women and children and not animals are at stake'.

It has been pointed out that, while the *total* population in India is increasing rapidly in many localities there has been a decrease or only a very slight increase. 'A decrease of this kind in a population like that of India is an ominous sign. There is no question of its being due to lessened birth rate, as it might be in a more spohisticated population, nor is it due to emigration on such a scale, and it must therefore be due to an excessive death rate. But an excessive death rate is not an isolated phenomenon and to every death there has been an equivalent amount of sickness interfering with the normal life of families, preventing the people tilling the ground, or collecting the harvests or tending the cattle on which the welfare of the rural population depends and so forth. It must inevitably mean loss of revenue, loss of general effectiveness of such populations and the deterioration of the resources of the affected areas. The cost of such deterioration could no doubt be assessed, but apart from this it is due to the population so affected that they should, as far as possible, be preserved from such results' (Christophers, 1924)

'It is not an exaggeration to say that 20,000,000 lives could have been saved in India this century by spending on prophylaxis considerably less than the disease itself must have cost' (Mégroz, 1931).

An extract from the appeal made to the Greek Government by the Greek Anti-Malaria League, Athens, in 1907, may be quoted verbatim as applicable to Indian conditions.

'The damage, then, inflicted by malaria is manifold. While it increases the death rate and checks the growth of population, it also ruins the quality of the present as well as the coming generation, lessens the resisting power of individuals and their capacity for work, and so contributes very largely to the increase of poverty and its attendant evils. Tens of millions must be the amount that is wasted yearly in the expense of nursing, through the idleness of the sick, the imperfect work of the cachectic, and the uncultivated land; the Italians rightly look upon their losses as exceeding the interest on the national debt'....... 'Malaria is the sword of Damocles hanging above our heads. It chokes the rising generation, drains the strength of the adults, lays waste our fields and weakens the arms of our warriors. Numbers of soldiers have fallen victims to fevers. I wish to say besides that these same malarial fevers are crushing the nation body and soul, and fostering among us idleness and all the evils that spring from idleness. Breathing their poisonous breath upon the face of the Greek land they shorten by one-half the life of the nation, and, like Harpies, defile all that they cannot devour or snatch away' (Jones, 1909).

It will be evident from the numerous quotations which have been given in this paper, that the views expressed here, as to the great menace which malaria forms to the population and the prosperity of all countries where the disease is prevalent, are not merely personal ones. They have been endorsed by workers from all parts of the world.

While India has done much in the past towards the solution of the problem of malaria prevention, much, alas too much, still remains to be done to alleviate the sufferings of her unfortunate rural population, and at the same time to help in the development of her natural resources, aspirations and prosperity.

(IV) CONCLUSIONS.

Among urban populations and special collections of people the provision of permanent anti-malarial measures is a paying proposition, and often the money invested yields a very high dividend through the benefits produced by such work.

Whatever steps be adopted to control malaria, the provision and distribution of adequate treatment for the malarious sick is the primary duty of every Government and administration.

While the direct financial benefits of anti-malarial measures in rural areas and among scattered populations are not always immediately apparent, the indirect effects of such work lead to a rise in the economic, social and intellectual status of the people. The increased prosperity which results in the end, makes such measures a paying proposition.

The institution of more active measures for the eradication and amelioration of malarial conditions in many areas of India, has now become an economic and national necessity. If India is to find room and employment for her increasing population, is to provide an adequate food supply for her teeming millions, is to develop to their fullest extent her natural resources, and is to achieve that prosperity and national progress for which she hopes, the malaria problem must be tackled at once by all the weapons she can muster for the attack.

In conclusion the words of Hoffman (1928) may be quoted :—

'The cause of malaria eradication, therefore, rests upon sound economic as well as self-evident humane considerations, leaving no escape from the final conclusion that the entire subject most urgently demands the qualified and intelligent co-ordination of all existing governmental agencies and related health-conserving activities, on the one hand, and a broad-minded public policy, on the other, with special reference, however, to the expenditures on behalf of local anti-malarial measures on the part of the general public. For economic reasons alone the effort would be worth while, since the economic results of effective anti-malarial measures are a foregone conclusion. The attainment of more or less complete malaria eradication throughout the country will require many years of intelligent, co-ordinated effort, sustained by liberal governmental appropriations, than which no nation in the world could make a better investment for the good of its citizenship than the United States. The fundamental principle of permanent success in malaria eradication is the intelligent and effective co-ordination of all measures and means, agencies and organisations, that can be utilised in the warfare against this most insidious foe of mankind. Whether it will require one or ten generations to secure measurably satisfactory

results will depend primarily upon the hearty and efficient co-operation of *all* governmental agencies, federal, state or municipal, and of the people themselves '.

Although these statements were made regarding the conditions in the United States, how much more highly are they applicable to India, where malarial conditions are so much more serious ?

G. GENERAL SUMMARY AND CONCLUSIONS.

Evidence has been produced to show that in India—

(1) Malaria by its effects upon the birth rate and on the death rate is a great, and probably the greatest, single cause in retarding the natural increase of the population.

(*a*) Malaria has a very marked action in lowering the birth rate by (*i*) reducing the numbers of conceptions, and by (*ii*) causing interruptions in pregnancy which result in abortions and still-births;

(*b*) Malaria is, in ordinary years, responsible directly for *at least* 1,000,000 deaths each year, and, in years when severe regional epidemics occur, this figure may be increased by another quarter of a million;

(*c*) Apart from this direct mortality, by its indirect action in lowering the general vitality of the afflicted, whereby many of them become more liable to contract other diseases, malaria is indirectly responsible for a very large number of additional deaths;

(*d*) Malaria by its direct and indirect actions is almost certainly responsible for *at least* 2,000,000 deaths each year.

(2) Malaria is probably the greatest factor in lowering the health, vitality and physical development of the people, in the areas where this disease prevails

(*a*) It is probable that *at least* 100 million persons suffer from the disease each year.

(*b*) It is probably responsible, through its effects in lowering the vitality of the sufferers, for an additional indirect morbidity of between 25 and 75 millions annually.

(*c*) It has a markedly deleterious influence upon the physical and mental development of both children and adults.

(*d*) It is a very important factor in the causation of the relatively low expectation of life in India.

(3) Malaria has the deplorable effect of hindering greatly the intellectual, social and national development of any people afflicted by it.

(4) Malaria gives rise to the greatest economic problem with which India is faced. The financial losses to the individual and the family alone have been calculated at *not less* than Rs. 11,000 lakhs annually, or about £80 million sterling per annum. This is apart from the effects of the disease upon all aspects of the labour problem, and thus upon the fullest exploitation of the natural resources of the country and the successful development of her manufacturing and other industries. While it is not possible to evaluate with any degree of accuracy the immensity of these direct and indirect losses, there is little reason to doubt that they must run into unbelievable millions of pounds sterling each year.

(*a*) The great financial losses to the individual, the family and the community through sickness and death from malaria have been discussed.

(*b*) It has been shown that malaria caused incalculable losses to agriculture, industry and commerce, mainly through its direct and indirect action upon different aspects of the labour problem. The most important industry of India, namely agriculture, is most markedly affected, and the disease gives rise to a retardation of agricultural development, and sometimes to the abandonment or decline of this work in very fertile, and potentially rich areas.

(5) The financial and economic losses which Governments and administrations have to bear through the effects of this disease have been shown. The disease not only results in a decrease of revenue but also in an increase in the cost of administration.

(6) Having taken these huge losses into account, it has been shown that wisely-planned anti-malarial operations are paying propositions, from which there is often a direct financial profit upon the money invested, and from which there is certainly an indirect profit in the effects which such measures have on the general prosperity of the community.

(7) It has been shown that, apart from all humanitarian aspects of the subject, the benefits which proper anti-malarial operations have upon the social, intellectual and economic progress of the people, make it the duty of every Government and administration to take all steps possible to promote energetic campaigns against this scourge.

From the evidence available one is justified in concluding that :—

The widespread prevalence of malaria is almost certainly the most serious economic and social problem of India. Others may be considered of secondary importance, in that most of them are directly and indirectly influenced to a very large extent by the protean effects of this disease

The labour problem and the malaria problem in India are synonymous, in that this disease is the main cause of the occurrence of inefficient and deficient labour. Through its effects on the labour problem, millions of acres remain uncultivated, or imperfectly cultivated, the natural wealth of the country cannot be fully exploited, and the progress of most industries is seriously hampered. This disease is a great, and probably the greatest, obstacle in the path of the attainment of those national, economic, social and intellectual aspirations, for the achievement of which the huge natural resources and enormous population of India would appear to fit her. *At least*, one hundred million persons suffer from, and one million succumb to, the *direct* ravages of this disease each year. What other social or economic problem is there the seriousness of which can be compared with the gravity of these facts and figures ?

The problem of existence in very many parts of India is the problem of malaria. There is no aspect of life in this country which is not affected, either directly or indirectly, by this disease. It constitutes one of the most important causes of economic misfortune, engendering poverty, diminishing the quantity and the quality of the food supply, lowering the physical and intellectual standard of the nation, and hampering increased prosperity and economic progress in every way.

If India is to obtain the full benefits of that national progress, which she hopes to attain and maintain under her new constitution, the problem of malaria is one which she must tackle immediately by all the means at her command.

This paper on 'What Malaria Costs India' has been written with the express intention of drawing much more attention to the very grave dangers which malaria places in the way of advancement in all aspects of life in India. The facts and deductions concerning the ravages which the disease causes to this country have been set forth and discussed in detail in relation to sanitary, medical, social, economic and other problems. Unfortunately in the past, the very great influence of malaria upon the solution of these problems has not been sufficiently appreciated by many people, even by so-called experts. Its fundamental relationship to these problems has often been obscured by other issues or glossed over in favour of other interests. It is hoped that the information given in this paper will stimulate a wider appreciation of the importance of this subject among those who have to deal with the many problems influenced by it.

It is only by a very close, whole-hearted and enthusiastic co-operation between all those agencies which are working for the advancement of the country, whether these be official or non-official, that one can hope to deal effectively with this radical factor in all India's social and economic problems. 'Those who are experts in these matters cannot render the Government, and the cause we are fighting for, a greater service than by keeping the real facts before the public. An educational mosquito and malaria propaganda has a far-reaching value, and in many other directions than merely mosquito and malaria control' (Hoffman, 1928).

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Records of the Malaria Survey of India, 6, 2, June, 1936.

A CLINICAL STUDY OF THE EFFECTS OF TREATING MALARIA WITH ATEBRIN AND ATEBRIN MUSONATE.

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[25th January, 1936.]

THIS investigation was undertaken in order to ascertain how quickly treatment of malaria patients with atebrin and atebrin musonate would restore their fitness for military duty, as judged by the clinical and parasitological effects obtained.

For this purpose, 25 patients suffering from various types of malaria were selected. These were all soldiers in the State Forces of His Highness the Maharaja of Patiala, and were treated in the Military Hospital, Patiala. The study of the clinical and parasitological observations followed closely the suggestions made by the Health Organisation of the League of Nations. The suggested data were collected and recorded on the charts issued by the latter organisation.

The total cases observed were 25 in number. They were all well-fed and in excellent general condition. None could be described as being either seriously ill or suffering from any complications. None of them was a case of fresh infection, as they had all suffered from previous attacks of malaria.

Type of infection.

B.T.*	S.T.*	Q.T.*	
3	4	1	
4	3	..	
4	5	..	
..	1	..	
11	13	1	Total: 25

*B.T. = infection with *P. vivax*.
S.T. = " " *P. falciparum*.
Q.T. = " " *P. malariae*.

For the purpose of treatment the patients were divided in three series as follows :—

Series I.—Eight cases received a subcutaneous injection of 0·75 mg. adrenaline (1: 1,000) followed half an hour later by an intramuscular injection of 0·375 gm. atebrin musonate. Twenty-four hours later a regular peroral course was commenced with atebrin tablets, 0·1 gm. thrice daily for five subsequent days.

All cases of this group were admitted with fever, which did not appear again after the treatment was started. None of these patients showed any unusual feature which should point to a complication. Case 7 showed signs of cerebral excitation on the day of administration of atebrin musonate. However, these signs were already noticed before the injection was given. He had also vomited before treatment was commenced.

Case 4 had a slight rise of temperature due to coryza.

In none of the cases was reappearance of parasites recorded.

The detailed results of the observations are recorded in the eight charts of Series I*.

Series II.—The treatment in the seven cases of this series was carried out as follows :—

A dose of 0·75 mg. adrenaline (1: 1,000) was injected subcutaneously, and, half an hour later, this was followed by an intramuscular injection of 0·375 gm. of atebrin musonate.

All cases of this group had fever on admission and, as indicated on the charts, fever reappeared in three out of seven cases of this series. No complications or toxic symptoms were observed. Case 13 had vomited before and on the day on which treatment was commenced.

Regarding the reappearance of parasites in the blood, the same species of Plasmodium as found before the commencement of treatment was detected again in case 12. The latter case also developed on the 14th day after commencement of the treatment a rise of temperature to a degree which necessitated a second adrenaline and atebrin musonate injection, after which no rise of temperature occurred during the following three days of observation.

Case 9 had a rise of temperature on the 6th day after the commencement of treatment. Although the blood was not examined for Plasmodia on that day, a relapse may safely be assumed; adrenaline and atebrin musonate were given and the temperature became normal. On the 10th day after commencement of treatment gametocytes were found, and at once a course of plasmoquine simplex was started in doses of 0·02 gm., thrice daily, for five subsequent days. The question whether the rise of temperature on the 6th day was due to a relapse of the primary type of infection, or to gametocytes, must be left open because no parasitological record is available.

Case 10 had a rise of temperature on the 5th day after commencement of treatment. Although no parasitological record is available, a relapse was assumed and adrenaline and atebrin musonate were given. No fever and no reappearance of parasites occurred afterwards.

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* Although on several charts 0·3 gm. atebrin is noted, it may be explained that actually 0·375 gm. of atebrin musonate was given.

Case 16 showed gametocytes on the 7th day after commencement of treatment, and a regular course of plasmoquine, 0·02 gm., was given thrice daily.

In case 13 also gametocytes were found on the 7th day after treatment was commenced, and he also was given a course of plasmoquine.

The other two cases of this group presented no feature of particular interest.

The details of the observations are given in the seven charts of Series II.

Series III.—This group of nine cases was treated with two intramuscular injections of atebrin musonate, the injections being separated by an interval of 24 hours*.

All the patients had fever on admission. Excepting case 24, who had a moderate rise of temperature on the second day after the first injection, *i.e.*, on the day following the second dose, none of them developed subsequently a temperature above normal.

Case 18 vomited on the day previous to, and on the day, when the first injection was given.

In case 17 the original species of parasites, both rings and gametocytes, were found again on the 7th day after commencement of treatment, *i.e.*, 5th day after the second injection, although a course of plasmoquine (0 02 gm., thrice daily, for five subsequent days) was started two days after the second atebrin-musonate dose. No clinical or parasitological relapses were noticed during the following period of observation of this patient.

Neither clinical nor parasitological relapses and complications were observed in any of the other cases.

One case, case 11, was given by mistake only one intramuscular injection of 0 375 gm. of atebrin musonate. On the 7th day after this injection gametocytes were found, but, after a course with plasmoquine, they were not seen again. This patient complained of vertigo for three days, 6th to 9th September, 1935, *i.e.*, from the 10th to the 13th day after injection.

The detailed observations of these cases are recorded in the nine charts of Series III.

CONCLUSIONS.

Twenty-five soldiers suffering from malaria, but otherwise in good general condition, were treated with different atebrin compounds. Two groups were also given injections of adrenaline in an attempt to force the parasites out of the internal organs into the general circulation, where the anti-plasmodial drug would have a better chance of acting upon them more quickly and completely.

The atebrin-musonate injection was given 30 minutes after the administration of adrenaline. This time was chosen because investigations of various authors and the experiments of one of us (S. F. S.) had previously shown that the culminating physiological general effect of adrenaline on blood pressure, pulse rate, blood sugar, circulating volume, etc., is found in normal individuals 25 to 45 minutes after the subcutaneous injection of 0·75–1 mg.

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* Blaze and Simeons (1935) had given two injections of 0·375 gm. atebrin musonate on two successive days and reported favourable results.

In a comparison of the effects of the three different methods of treatment under discussion, we shall have to consider the effect on

(*a*) the clinical condition, *i.e.*, occurrence of clinical relapse,

(*b*) parasitological findings, *i.e.*, the occurrence of parasitological relapse, and

(*c*) by-effects.

By comparing these different factors, it may be possible to give a fairly appropriate answer to the question of which particular method of treatment will give the best result for restoring fitness for military duty.

Beginning with the last point, the by-effects played so small a part in our cases that they may be neglected in drawing any conclusions from this investigation.

Series I (*eight cases*).

(*a*) Effect on clinical condition and on relapse.

It appears that the method of treatment employed in this group furnished the most favourable results (adrenaline 0·75 mg. subcutaneously; atebrin musonate 0·375 gm. intramuscularly; atebrin tablets 0·1 gm. thrice daily for five days starting 24 hours after the injection of atebrin musonate).

Fever disappeared in all cases within 24 hours after the injection and did not reappear during the period of observation.

(*b*) As regards the parasitological findings the same favourable result was recorded.

None of the cases showed reappearance of Plasmodia during the period from the commencement of treatment till the day of discharge from hospital.

Series II (*seven cases*).

(*a*) Effect on clinical condition.

The results obtained with this method (adrenaline 0·75 mg. subcutaneously and atebrin musonate 0·375 gm. intramuscularly) do not appear to be satisfactory. Three out of seven cases showed a considerable rise of temperature on various days after the injections were started.

(*b*) The reappearance of parasites in the blood suggests the same conclusion.

In two cases parasites were found after the injection, and only two cases out of seven showed a satisfactory result after treatment.

Series III (*nine cases*).

(*a*) Effect on clinical condition.

The method employed here (two intramuscular injections of atebrin musonate 0·375 gm. separated by an interval of 24 hours between the injections) gave more satisfactory results than the one described under Series II. One case only showed fever after treatment.

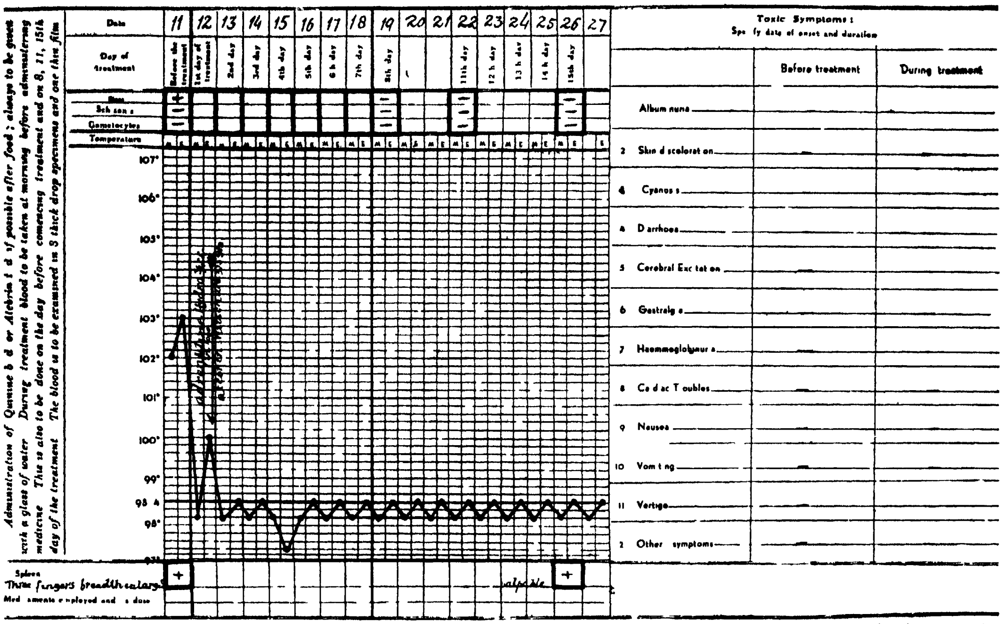
(*b*) The same favourable result was obtained in respect of reappearance of parasites in the blood. In one case only were Plasmodia found after treatment.

SUMMARY.

Comparison of clinical and parasitological data permits one to conclude that the method of administering adrenaline and atebrin musonate, followed by a peroral course with atebrin tablets, furnished the best results in the cases under review.

CONTROL OF MALARIA TREATMENT. B T +, Q T —, S. T — [*I Series*

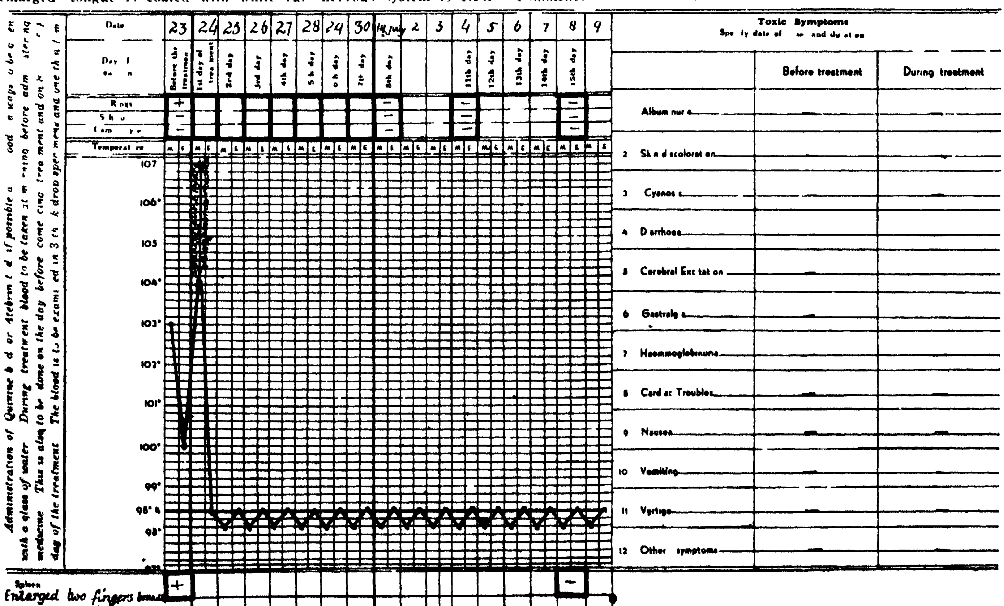
(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection?—No Name of Hospital.—Military Patient No —1st, Age —30 years, Sex —Male, Body Weight —112 lb Come from non malarious district?—Yes Patient's Name —Sp Kirpal Singh, Co D 1883. Father's Name —Budh Singh Address —2nd Infantry, Patiala Date of 1st Malarial attack —Nine years back Date of last attack —One year back Treatment during last attack —Quinine Mixture Treatment employed during present attack —Adrenaline and Atebrin combined NOTES on the Present Condition —Slightly anæmic, spleen hard and enlarged, nervous system clear, no pigmentation of skin Commence from —11th June, 1935 —Observation



¼ c.c. adrenaline (1: 1,000 hydro) injected; ½ hour later atebrin musonat 0 375 gm in 9 c c of distilled water injected Atebrin tablet 1½ gr (0 1 gm) t d s given for five days starting from 13th June 1935

CONTROL OF MALARIA TREATMENT B T +, Q T —, S T — [*I Series*

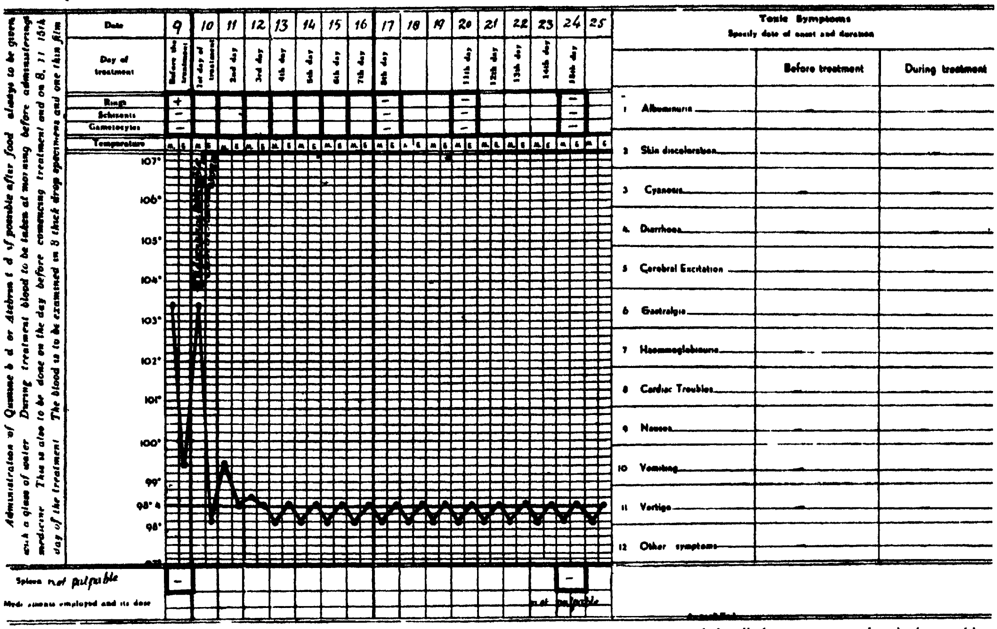
(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection?—No Name of Hospital —Military Patient No —2nd Age —30 years Sex —Male Body Weight —116 lb Come from non malarious district?—Yes Patient's Name —Bachan Singh Sq C 2599 Father's Name —Fatti Singh Address —1st Rajinder Lancers Patiala Date of 1st Malarial attack —Six years back Date of last attack —Two years back Treatment during last attack —Quinine Mixture Treatment employed during present attack —Adrenaline and Atebrin combined NOTES on the Present Condition —No anæmia spleen is hard and enlarged tongue is coated with white fur nervous system is clear Commence from —23rd June 1935 —Observation



¼ c.c. adrenaline (1: 1,000 hydro) injected; ½ hour later atebrin musonat 0 375 gm in 9 c c of distilled water injected Atebrin tablet 1½ gr (0 1 gm), three times a day for five days, starting from 25th June, 1935.

CONTROL OF MALARIA TREATMENT. B. T. +; Q. T.—; S. T. —. [I. Series.

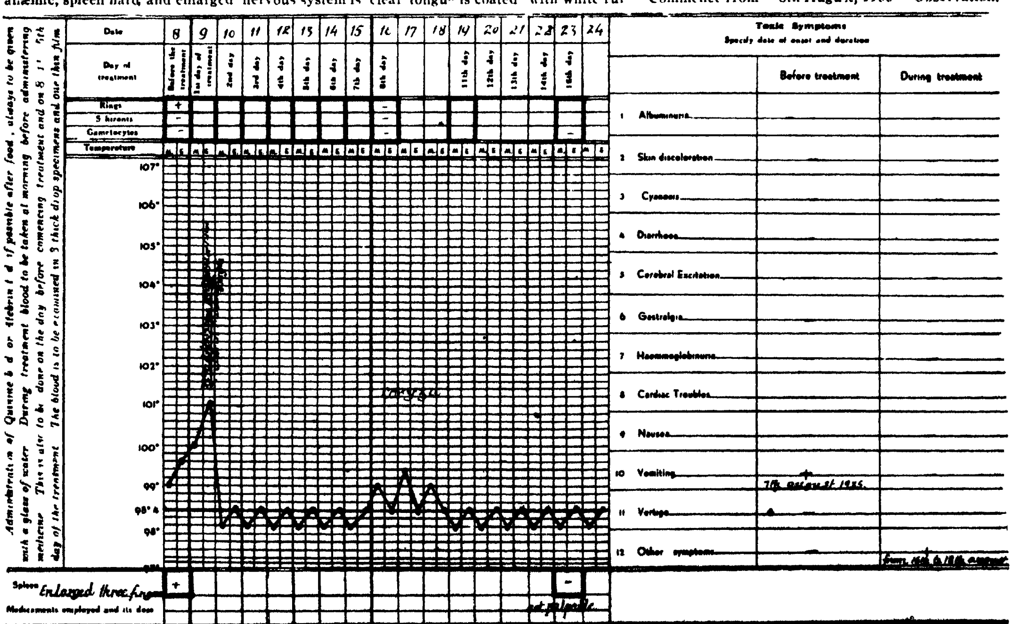
(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital.—Military. Patient No.—3rd; Age.—23 years; Sex.—Male; Body Weight.—112 lb. Come from non-malarious district?—Yes. Patient's Name.—Joginder Singh, Sq. C. 2765. Father's Name.—Rattan Singh. Address.—1st Rajinder Lancers, Patiala. Date of 1st Malarial attack.—Ten years back. Date of last attack.—Two years back. Treatment during last attack.—Quinine Mixture. Treatment employed during present attack.—Adrenaline and Atebrin combined. NOTES on the Present Condition.—No anæmia, no enlargement of spleen or liver, nervous system is clear, tongue is clean and moist. Commence from —9th August, 1935.—Observation



½ c.c adrenaline (1: 1,000 hydro) injected and after ½ hour atebrin musonat 0.375 gm in 9 c.c of distilled water injected. Atebrin tablets 1½ gr (0.1 gm), given thrice daily for five days, starting from 11th August, 1935

CONTROL OF MALARIA TREATMENT. B T +, Q T —, S T — [I Series.

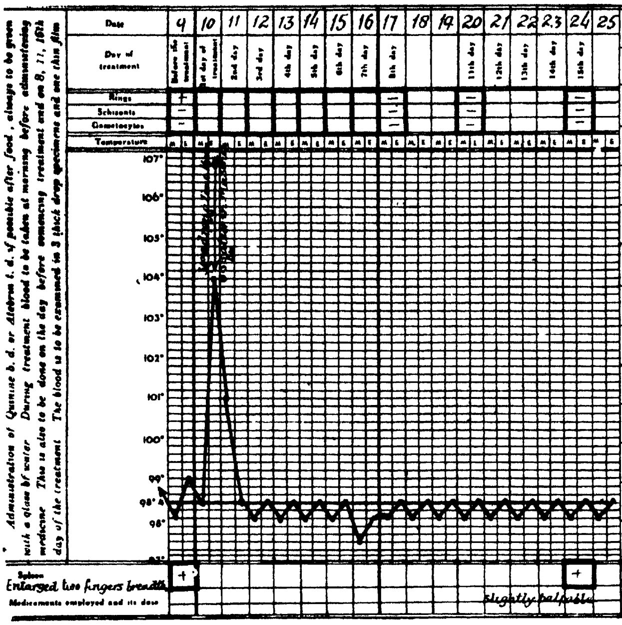
(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection?—No. Name of Hospital—Military Patient No—4th, Age—23 years, Sex—Male, Body Weight 130 lb Come from non-malarious district?—Yes Patient's Name—Sr Joginder Singh, Sq C 2627 Father's Name Harnam Singh Address—1st Rajinder Lancers, Patiala Date of 1st Malarial attack—Six years back Date of last attack Four months back Treatment during last attack Quinine Mixture Treatment employed during present attack—Adrenaline and Atebrin combined NOTES on the Present Condition Slightly anæmic, spleen hard and enlarged nervous system is clear tongue is coated with white fur Commence from 8th August, 1935 - Observation.



½ c.c. adrenaline (1: 1,000 hydro) injected; ½ hour later atebrin musonat 0.375 gm. injected. Atebrin tablet 1½ gr. (0.1 gm.) given thrice a day for five days, starting from 9th August, 1935.

CONTROL OF MALARIA TREATMENT. B. T. +; Q. T.— ; S. T. —. [I. Series

(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital.—Military. Patient No.—5th; Age.—28 years; Sex.—Male; Body Weight.—112 lb. Come from non-malarious district?—Yes. Patient's Name.—L. Dewa Singh, Co D 1613. Father's Name.—Bishen Singh. Address.—2nd Infantry, Patiala. Date of 1st Malarial attack.—Twelve years back. Date of last attack.—Four months back. Treatment during last attack.—Quinine Mixture. Treatment employed during present attack.—Adrenaline and Atebrin combined. NOTES on the Present Condition.—Slightly anæmic, spleen is enlarged, nervous system clear, tongue is coated with fur, no pigmentation of skin. Commence from.—9th August, 1935.—Observation.

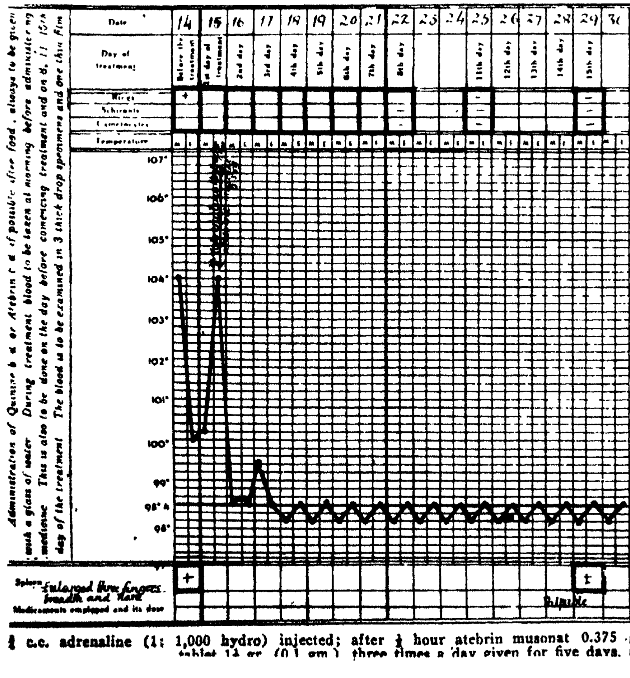


Toxic Symptoms: Specify date of onset and duration	Before treatment	During treatment
1. Albuminuria	—	
2. Skin discoloration	—	
3. Cyanosis	—	
4. Diarrhoea	—	
5. Cerebral Excitation	—	
6. Gastralgia	—	
7. Haemmoglobinuria	—	
8. Cardiac Troubles	—	
9. Nausea	—	
10. Vomiting	—	
11. Vertigo	—	
12. Other symptoms	—	

¾ c.c. adrenaline (1: 1,000 hydro) injected; ½ hour later atebrin musonat 0.375 gm. in 9 c.c. of distilled water injected. Atebrin tablet 1½ gr. (0.1 gm.), given thrice a day for five days, starting from 11th August, 1935.

CONTROL OF MALARIA TREATMENT. B. T. +; Q. T.— ; S. T. - -. [I. Series.

(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital.—Military. Patient No.—6th; Age.—21 years; Sex Male; Body Weight.—112 lb. Come from non-malarious district?—Yes. Patient's Name.—Driver Gurbax Singh, Sec. 1, 1230. Father's Name. Jhagharoo. Address.—Transport Train, Patiala. Date of 1st Malarial attack.—Nine years back. Date of last attack.—Eight months back. Treatment during last attack.—Quinine Mixture. Treatment employed during present attack.—Adrenaline and Atebrin combined. NOTES on the Present Condition No anæmia, spleen is hard and enlarged, liver and nervous system normal, tongue is coated with white fur. Commence from. 14th August, 1935.—Observation.



Toxic Symptoms: Specify date of onset and duration	Before treatment	During treatment
1. Albuminuria		
2. Skin discoloration		
3. Cyanosis		
4. Diarrhoea		
5. Cerebral Excitation		
6. Gastralgia		
7. Haemmoglobinuria		
8. Cardiac Troubles		
9. Nausea		
10. Vomiting		
11. Vertigo		
12. Other symptoms		

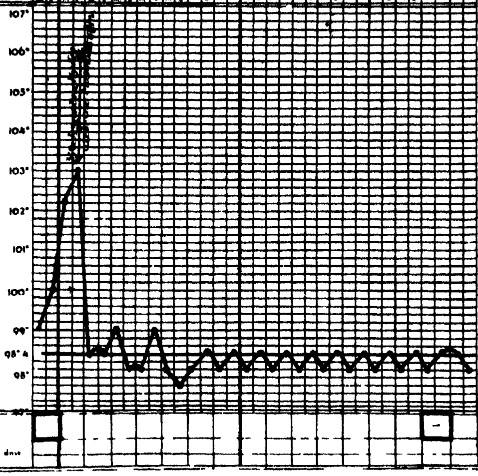
¾ c.c. adrenaline (1: 1,000 hydro) injected; after ½ hour atebrin musonat 0.375 gm. in 9 c.c. of distilled water injected. Atebrin tablet 1½ gr. (0.1 gm.) three times a day given for five days, starting from 16th August, 1935.

CONTROL OF MALARIA TREATMENT. B. T. +; Q. T.— ; S. T. —. [I. *Series.*

(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital.—Military. Patient No.—7th; Age.—19 years; Sex.—Male; Body Weight.—116 lb. Come from non-malarious district?—Yes. Patient's Name.—Rec. Dalip Singh, Co D, 2158. Father's Name.—Bharpoor Singh. Address.—2nd Infantry, Patiala. Date of 1st Malarial attack.—Six years back. Date of last attack.—One year back Treatment during last attack.—Quinine Mixture. Treatment employed during present attack.—Adrenaline and Atebrin combined. NOTES on the Present Condition.—Slightly anæmic, no enlargement of liver or spleen, nervous system clear, tongue is coated with white fur. Commence from.—17th August, 1935.—Observation.

Administration of Quinine b d or Atebrin t d if possible after food, always to be given with a glass of water During treatment blood to be taken at morning before administering medicine This is also to be done on the day before commencing treatment and on 8, 11, 15th day of the treatment The blood is to be examined in 3 thick drop specimens and one thin film

Date	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1st Sep	2
Day of treatment	Before the treatment	1st day of treatment	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day			11th day	12th day	13th day	14th day	15th day	
Rings	+								—			—				—	
Schizonts	—								—			—				—	
Gametocytes	—								—			—				—	
Temperature	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E



Spleen not enlarged

Medicaments employed and its dose

Toxic Symptoms: Specify date of onset and duration	Before treatment	During treatment
1 Albuminuria		
2 Skin discoloration		
3 Cyanosis		
4 Diarrhoea		
5 Cerebral Excitation		On 18th August 1935
6 Gastralgia		
7 Haemmoglobinuria		
8 Cardiac Troubles		
9 Nausea		
10 Vomiting	On 16th August 1935	
11 Vertigo		
12 Other symptoms		

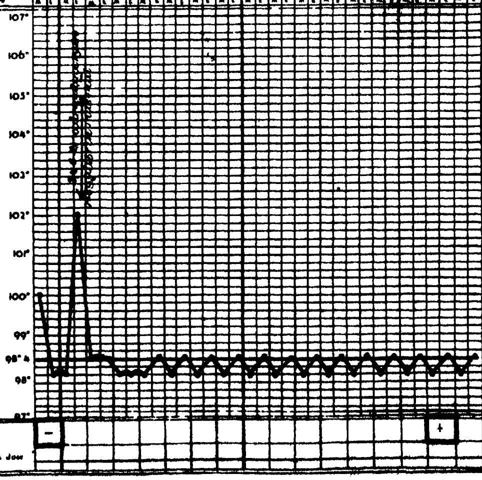
½ c.c. adrenaline (1: 1000 hydro) injected, after ½ hour atebrin musonat 0.375 gm in 9 c.c. of distilled water injected Atebrin tablet 1½ gr (0.1 gm) three times a day given for five days, starting from 19th August 1935.

CONTROL OF MALARIA TREATMENT. B T +, Q T --, S. T . [I *Series.*

(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection? No. Name of Hospital Military Patient No 8th Age 30 years, Sex Male, Body Weight — 126 lb. Come from non malarious district? Yes Patient's Name Sp Chhota Singh, Co B 1275 Father's Name - Partap Singh Address 1st Infantry, Patiala Date of 1st Malarial attack - Fifteen years back. Date of last attack One year back Treatment during last attack Quinine Mixture Treatment employed during present attack - Adrenaline and Atebrin combined NOTES on the Present Condition Patient is fairly developed, no enlargement of liver and spleen, no pigmentation, nervous system is clear Commence from — 17th August, 1935. Observation

Administration of Quinine b d or Atebrin t d if possible after food always to be given with a glass of water During treatment blood to be taken at morning before administering medicine This is also to be done on the day before commencing treatment and on 8, 11, 15th day of the treatment The blood is to be examined in 3 thick drop specimens and one thin film

Date	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1st Sep	2
Day of treatment	Before the treatment	1st day of treatment	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day			11th day	12th day	13th day	14th day	15th day	
Rings	+								—			—				—	
Schizonts	—								—			—				—	
Gametocytes	—								—			—				—	
Temperature	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E



Spleen Not enlarged

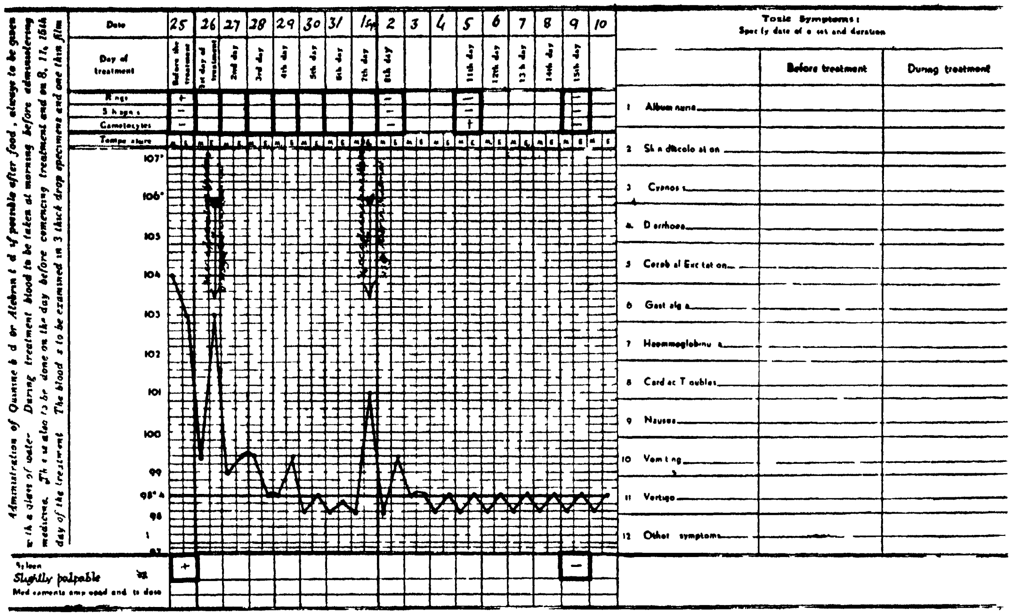
Medicaments employed and its dose

Toxic Symptoms: Specify date of onset and duration	Before treatment	During treatment
1 Albuminuria		
2 Skin discoloration		
3 Cyanosis		
4 Diarrhoea		
5 Cerebral Excitation		
6 Gastralgia		
7 Haemmoglobinuria		
8 Cardiac Troubles		
9 Nausea		
10 Vomiting		
11 Vertigo		
12 Other symptoms		

½ c.c. adrenaline (1: 1,000 hydro) injected; after ½ hour atebrin musonat 0.375 gm. injected in 9 c.c. of distilled water. Atebrin tablet 1½ gr. (0.1 gm.), given three times a day for five days, starting from 19th August, 1935.

CONTROL OF MALARIA TREATMENT. B T +, Q T —, S T — [II Series

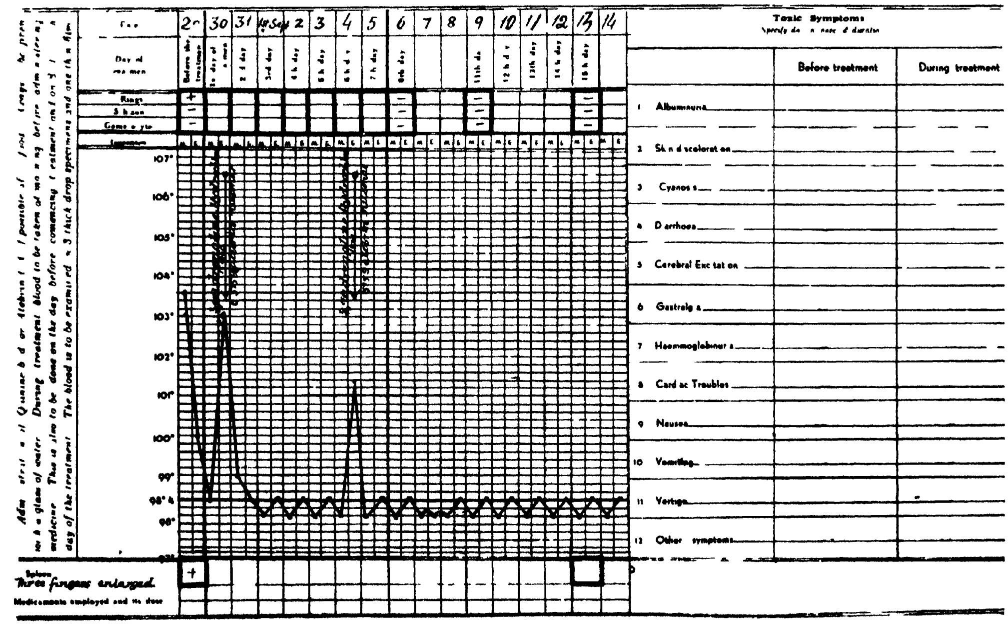
(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection?—No. Name of Hospital—Military. Patient No—9th, Age—24 years, Sex—Male, Body Weight—142 lb Come from non malarious district?—Yes. Patient's Name—Sp. Balwant Singh, H Q. W 2175. Father's Name—Kishen Singh Address—1st Infantry, Patiala Date of 1st Malarial attack—Ten years back Date of last attack—One year back Treatment during last attack—Quinine Mixture Treatment employed during present attack—Adrenaline and Atebrin musonat NOTES on the Present Condition—Not anæmic, spleen is slightly palpable, no pigmentation, nervous system is clear Commence from 25th August 1935- Observation



§ c.c. adrenaline (1 1000 hydro) injected ½ hour later atebrin musonat 0 375 gm in 9 c.c. distilled water injected Repeated on 1st September 1935 due to second rise of temperature plasmoquin 0 02 gm tablets given t.d.s. for five days starting on 5th September 1935

CONTROL OF MALARIA TREATMENT B T + Q T — S T [II Series

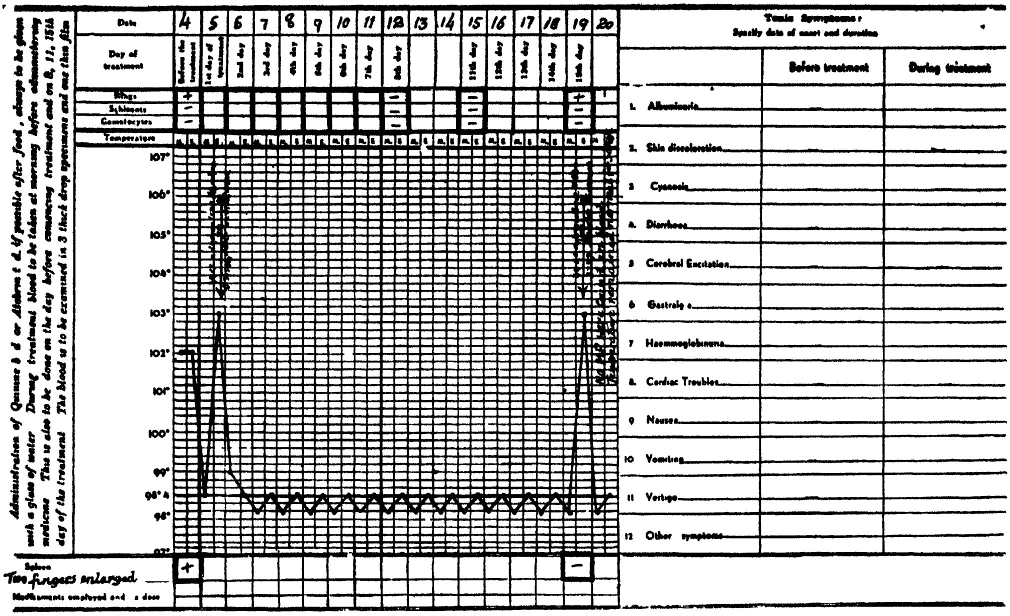
(According to the suggestion of The Bureau of Hygiene League of Nations) Is this the first infection? No Name of Hospital Military Patient No 10th Age 24 years Sex Male Body Weight 1 lb Come from non malarious district?—Yes Patient's Name L N Harchand Singh D 1973 Father's Name Nagan Singh Address 1st Infantry Patiala Date of 1st Malarial attack Eight years back Date of last attack One year back Treatment during last attack Quinine Mixture Treatment employed during present attack Adrenaline and Atebrin musonat NOTES on the Present Condition Patient is anæmic and thin spleen is enlarged nervous system is clear no pigmentation of skin Commence from 29th August 1935 Observation



§ c.c. adrenaline (1 1000 hydro) injected; ½ hour before atebrin musonat on 30th August 1935, and 4th September, 1935, respectively. 0 375 gm. atebrin musonat in 9 c c. distilled water injected Repeated on 4th September, 1935, on rise of temperature.

CONTROL OF MALARIA TREATMENT. B. T +; Q. T —; S. T —, (II. Seri

(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital—Military. Patient No—12th, Age—26 years; Sex—Male; Body Weight—136 lb. Come from non-malarious district?—Yes Patient's Name—Sp Mir Baz Co A 1922 Father's Name—Bahadur Ali. Address—2nd Infantry, Patiala. Date of 1st Malarial attack—Twelve years back Date of last attack—Three years back Treatment during last attack—Private Medicine. Treatment employed during present attack—Adrenaline and Atebrin musonat NOTES on the Present Condition—No anæmia, no pigmentation of skin, nervous system is clear, spleen enlarged Commence from—4th September, 1935—Observation

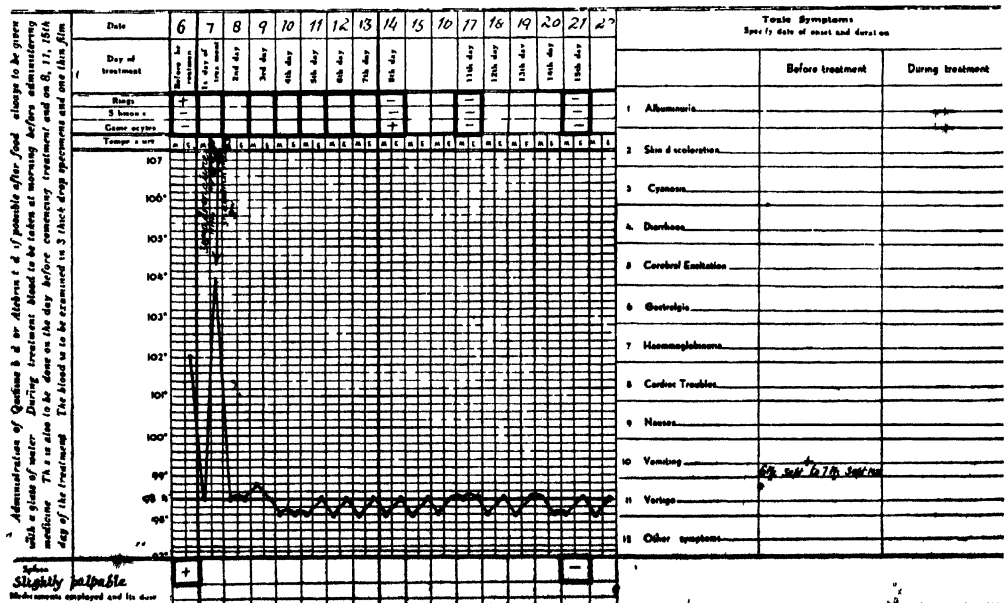


$\frac{1}{2}$ c c adrenaline (1 1 000 hydro) injecte

15th day

CONTROL OF MALARIA TREATMENT B T + Q T S T — (II Series

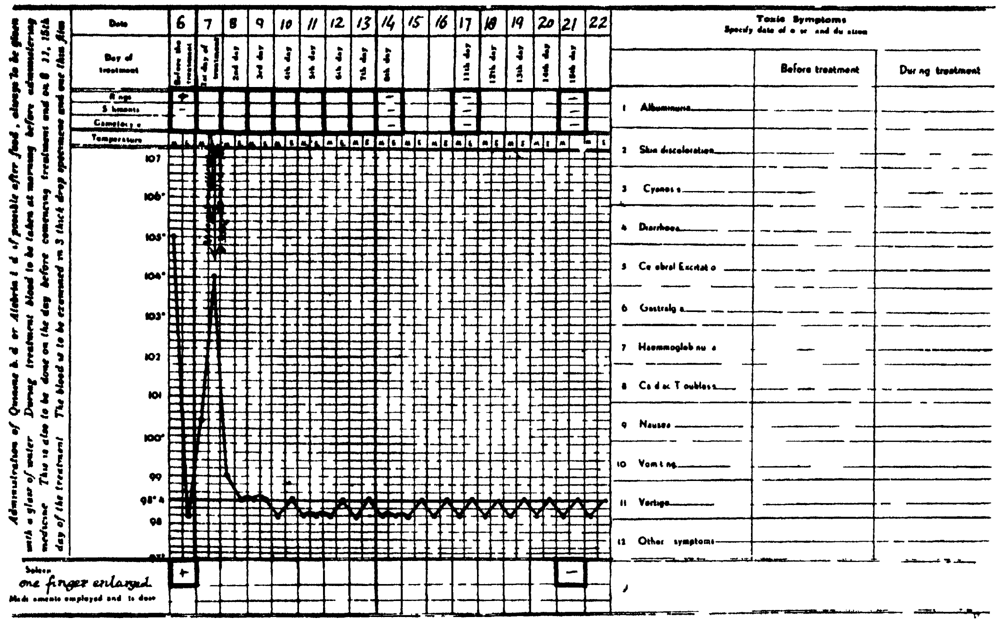
(According to the suggestion of The Bureau of Hygiene League of Nations) Is this the first infection? No Name of Hospital—Military Patient No 13th Age—22 years Sex Male Body Weight 119 lb Come from non malarious district?—Yes Patient's Name Sp Kirtar Singh H Q W 2302 Father's Name Chuni Singh Address 1st Infantry Patiala Date of 1st Malarial attack Eight years back Date of last attack One month back Treatment during last attack Quinine Mixture Treatment employed during present attack Adrenaline and Atebrin musonat NOTES on the Present Condition No anæmia no pigmentation of skin spleen palpable nervous system clear Commence from—6th September 1935 Observation



$\frac{1}{2}$ c.c. adrenaline (1 : 1,000 hydro) injected, $\frac{1}{2}$ hour later atebrin musonat 0.375 gm in 9 c.c. of distilled water injected.

CONTROL OF MALARIA TREATMENT. B T +, Q T —; S T — [II Series

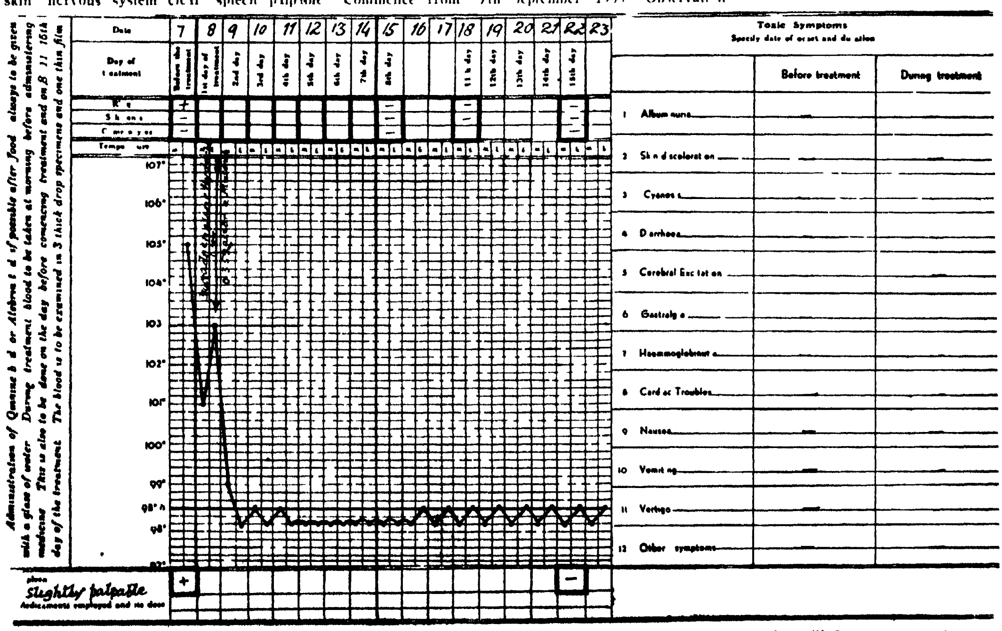
(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection?—No Name of Hospital—Military Patient No—14th, Age.—25 years, Sex—Male, Body Weight—108 lb Come from non malarious district?—Yes. Patient's Name—Sp Narinder Singh, H Q W 2266 Father's Name—Hamel Singh Address—1st Infantry Patiala Date of 1st Malarial attack.—Ten years back Date of last attack—One month back Treatment during last attack—Quinine Mixture Treatment employed during present attack—Adrenaline and Atebrin musonat NOTES on the Present Condition—No anæmia no pigmentation of skin, nervous system is clear, spleen is enlarged Commence from—6th September 1935—Observation



¾ c c adrenaline (1 1 000 hydro) injected ½ hour later atebrin musonat 0 375 gm in 9 c c of distilled water injected

CONTROL OF MALARIA TREATMENT B T + Q T — S T — [II Series

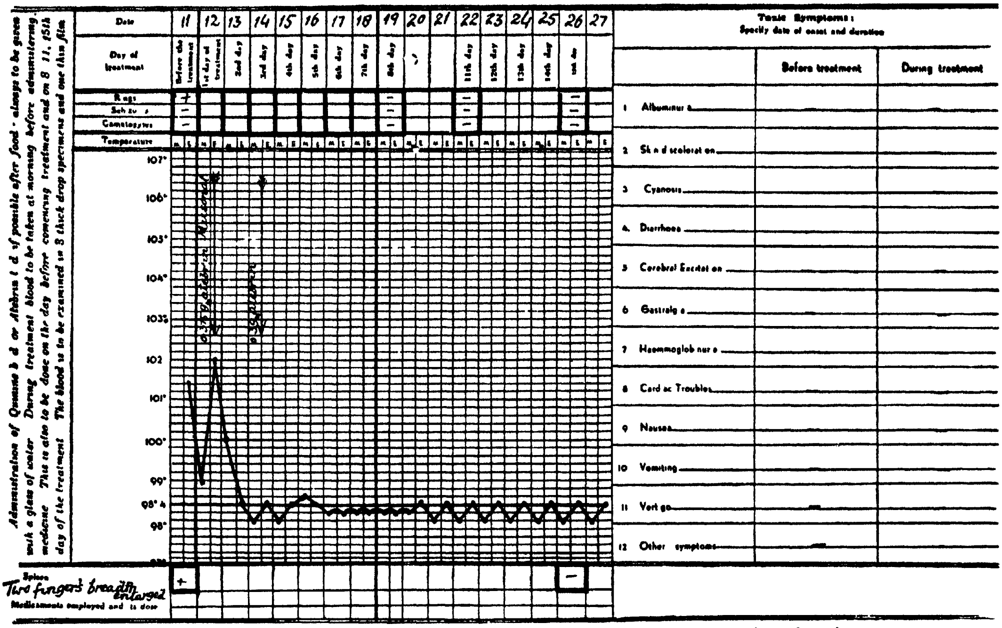
(According to the suggestion of The Bureau of Hygiene League of Nations) Is this the first infection?—No Name of Hospital Military Patient No 15th Age 31 years Sex Male Body Weight 120 lb Come from non malarious district?—Yes Patient's Name Sp Uttam Singh H Q W 1388 Father's Name Pirtab Singh Address 1st Infantry Patiala Date of 1st Malarial attack Eleven years back Date of last attack Two years back Treatment during last attack Quinine Mixture Treatment employed during present attack Adrenaline and Atebrin musonat NOTES on the Present Condition—No anæmia no pigmentation of skin nervous system clear spleen palpable Commence from 7th September 1935 Observation



¾ c.c. adrenaline (1 · 1,000 hydro) injected; ½ hour later atebrin musonat 0 375 gm. in 9 c c of distilled water injected

CONTROL OF MALARIA TREATMENT. B T. +; Q. T.—; S. T.—. [III. Series.

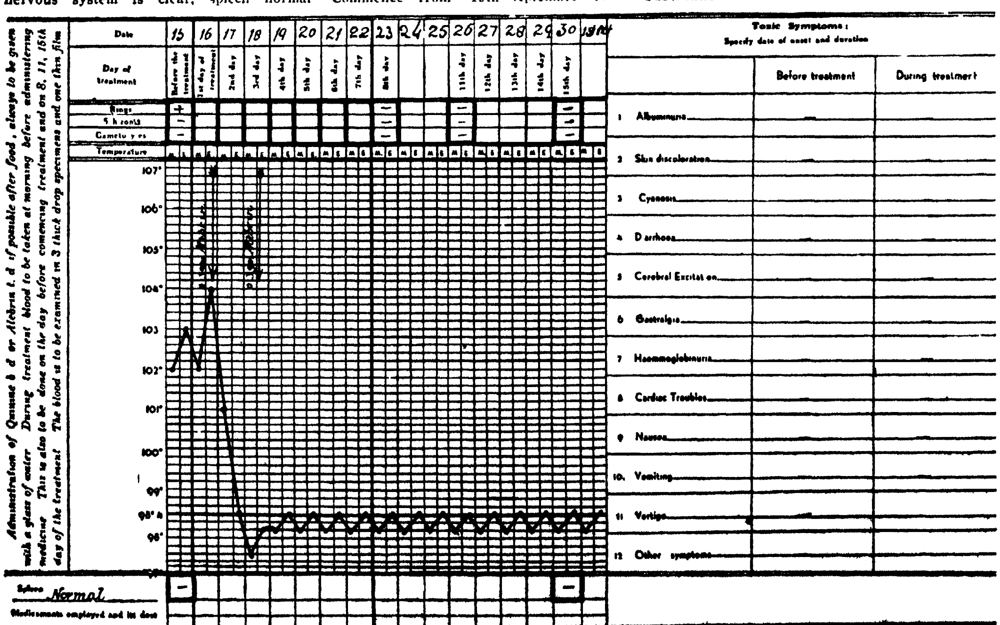
(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital—Military Patient No—20th; Age—23 years; Sex—Male; Body Weight—128 lb. Come from non-malarious district?—Yes Patient's Name.—Sr. Uttam Singh, Sq. C 1895 Father's Name.—Sunder Singh. Address.—1st Rajinder Lancers, Patiala. Date of 1st Malarial attack.—Twelve years back. Date of last attack—Two years back. Treatment during last attack.—Quinine Mixture. Treatment employed, during present attack—Atebrin musonat. NOTES on the Present Condition—No anæmia, no pigmentation of skin, nervous system is clear, spleen is enlarged Commence from.—11th September, 1935.—Observation



0 375 gm atebrin musonat in 9 c c of distilled water injected and repeated on third day

CONTROL OF MALARIA TREATMENT B T +, Q T—, S T— [III Series.

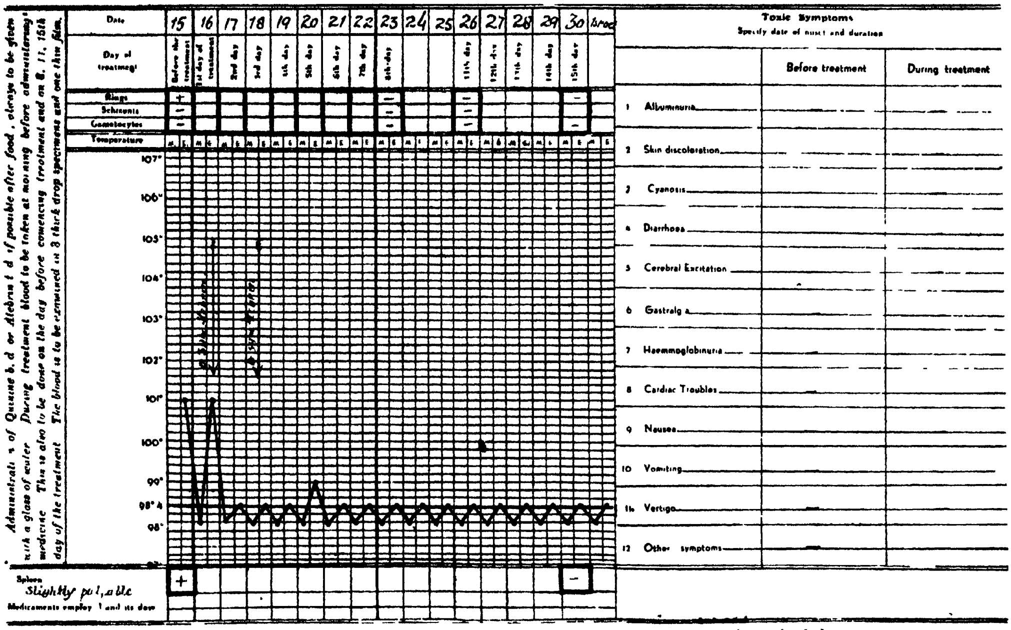
(According to the suggestion of 'The Bureau of Hygiene League of Nations) Is this the first infection? —No. Name of Hospital—Military Patient No—21st Age 37 years Sex Male, Body Weight 126 lb Come from non malarious district?—Yes Patient's Name—Sp Kishen Singh, Co B 1115 Father's Name—Laiq Ram Address 1st Infantry Patiala Date of 1st Malarial attack—Thirteen years back Date of last attack Seven years back Treatment during last attack—Quinine Mixture Treatment employed during present attack—Atebrin musonat NOTES on the Present Condition—No anæmia no pigmentation of skin, nervous system is clear, spleen normal Commence from—15th September 1935—Observation



0.3 gm. atebrin in 9 c.c. of distilled water injected, and repeated on third day.

CONTROL OF MALARIA TREATMENT. B. T. +; Q. T.— ; S. T. —. [*III. Series.*

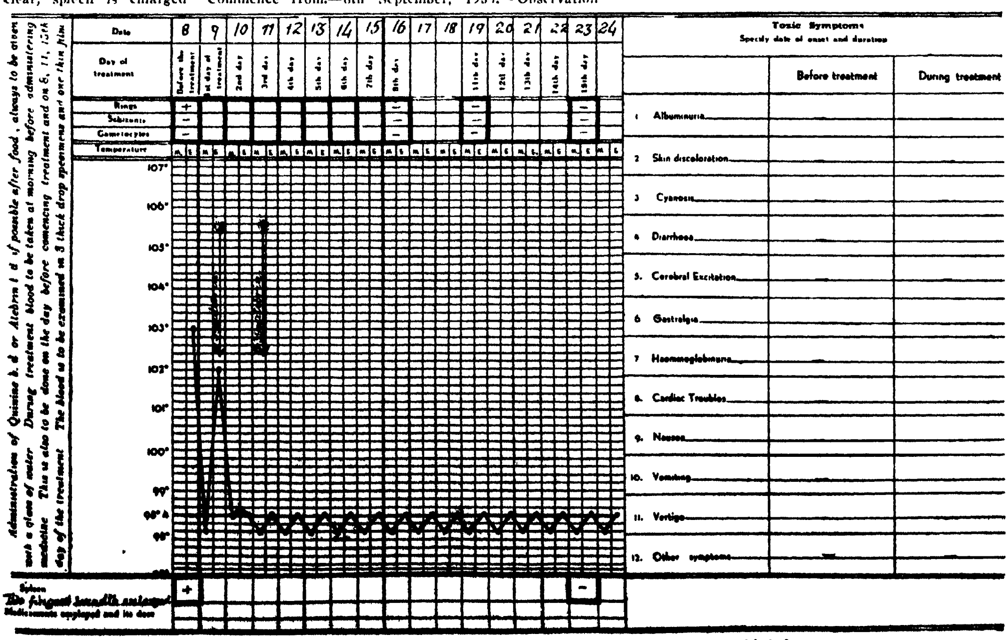
(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital.—Military. Patient No.—22nd; Age.—32 years; Sex.—Male; Body Weight.—124 lb. Come from non-malarious district?—Yes. Patient's Name.—Sp. Natha Singh, Co A. 1507. Father's Name.—Sunder Singh. Address.—1st Infantry, Patiala. Date of 1st Malarial attack.—Ten years back. Date of last attack.—Two years back. Treatment during last attack.—Quinine Mixture. Treatment employed during present attack.—Atebrin musonat. NOTES on the Present Condition.—No anæmia, no pigmentation of skin, nervous system is clear, spleen is slightly enlarged. Commence from.—15th September, 1935.—Observation.



0.3 gm. atebrin in 9 c.c. of distilled water injected and repeated on third day.

CONTROL OF MALARIA TREATMENT. B. T +; Q. T — ; S. T —. [*III. Series.*

(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection?—No. Name of Hospital – Military Patient No —23rd, Age.—28 years; Sex — Male; Body Weight —124 lb. Come from non malarious district?—Yes Patient's Name – Sp Charat Singh Co B 1892. Father's Name Nanak Singh Address. –1st Infantry, Patiala Date of 1st Malarial attack —Eleven years back. Date of last attack.—One year back Treatment during last attack.—Quinine Mixture. Treatment employed during present attack. –Atebrin musonat NOTES on the Present Condition.– No anæmia, no pigmentation, nervous system is clear, spleen is enlarged Commence from.—8th September, 1935.—Observation

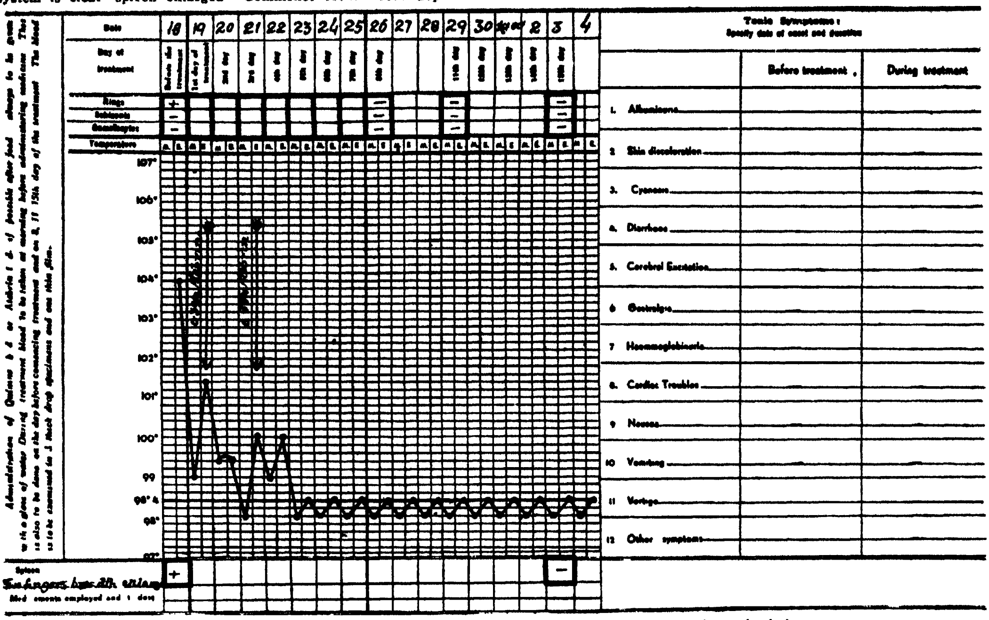


0.3 gm. atebrin in 9 c.c. distilled water injected and repeated on third day.

CONTROL OF MALARIA TREATMENT.

B. T +, Q. T —; S. T —. [illegible] Series

(According to the suggestion of "The Bureau of Hygiene", League of Nations) Is this the first infection?—No. Name of Hospital —Military Patient No —24th, Age —25 years; Sex.—Male, Body Weight.—140 lb. Come from non malarious district?—Yes Patient's Name —Hav Ujjagar Singh Co C 1889 Father's Name —Mastan-Singh Address —2nd Infantry, Patiala. Date of 1st Malarial attack —Six years back Date of last attack —Three years back Treatment during last attack —Quinine Mixture. Treatment employed during present attack —Atebrin musonat NOTES on the Present Condition —No anæmia no pigmentation of skin, nervous system is clear spleen enlarged Commence from —18th September 1935 —Observation

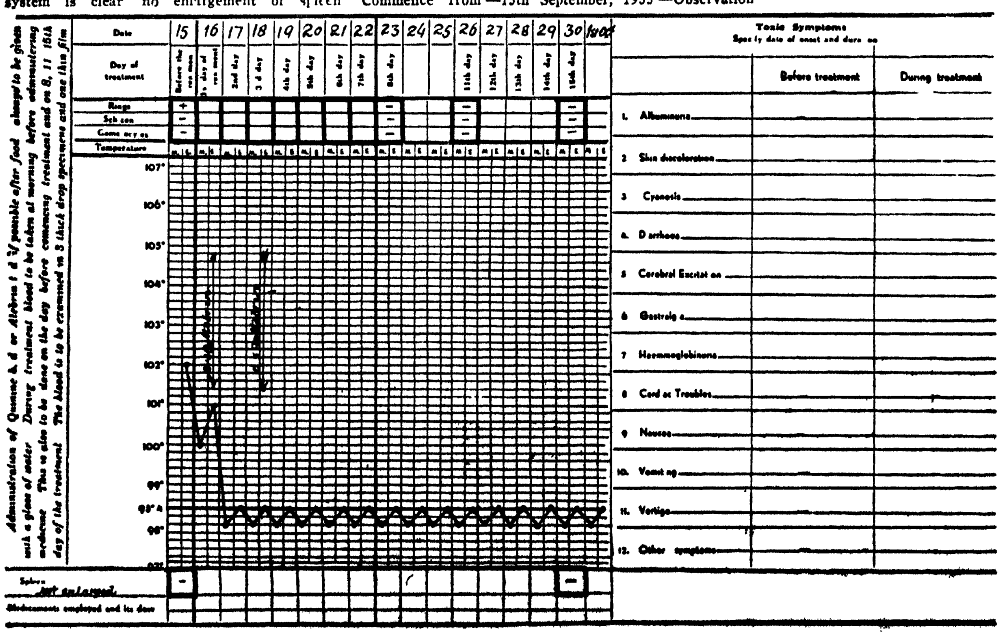


0.3 gm atebrin in 9 c.c. of distilled water injected and repeated on third day

CONTROL OF MALARIA TREATMENT

B T + Q T — S T — III Series

(According to the suggestion of The Bureau of Hygiene League of Nations) Is this the first infection? No Name of Hospital —Military Patient No —25th Age 26 years Sex Male Body Weight 126 lb Come from non malarious district?—Yes Patient's Name —Sp Gulzara Singh Co A 2686 Father's Name —Malla Singh Address 3rd Infantry Patiala Date of 1st Malarial attack —Fifteen years back Date of last attack —One month back Treatment during last attack Quinine Mixture Treatment employed during present attack —Atebrin musonat NOTES on the present Condition No anæmia no pigmentation of skin nervous system is clear no enlargement of spleen Commence from —15th September, 1935 —Observation



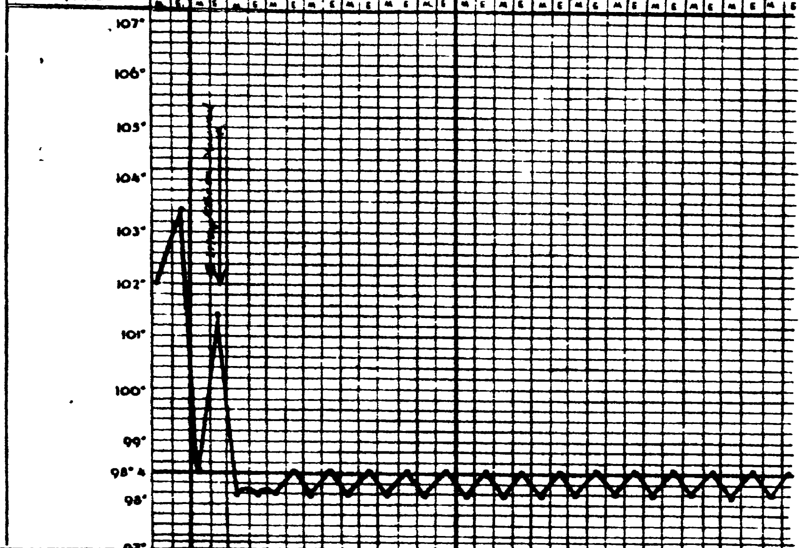
0.3 gm atebrin in 9 c.c. of distilled water injected and repeated on third day.

CONTROL OF MALARIA TREATMENT. B. T +. Q. T.— ; S. T. —.

(According to the suggestion of "The Bureau of Hygiene", League of Nations). Is this the first infection?—No. Name of Hospital.—Military. Patient No.—11th; Age.—30 years; Sex.—Male; Body Weight.—106 lb. Come from non-malarious district?—Yes. Patient's Name.—Sr. Mehar Mohd, Sq. B. 2334 Father's Name.—Bhumbe Khan. Address.—1st Rajinder Lancers, Patiala. Date of 1st Malarial attack.—Ten years back. Date of last attack.—One month back. Treatment during last attack.—Quinine Mixture. Treatment employed during present attack.—Atebrin musonat. NOTES on the Present Condition.—Constitution weak, spleen enlarged, no pigmentation of skin, nervous system is clear. Commence from.—26th August, 1935.—Observation.

Administration of Quinine b. d or Atebrin t d if possible after food; always to be given with a glass of water. During treatment blood to be taken at morning before administering medicine. This is also to be done on the day before commencing treatment and on 8, 11, 15th day of the treatment. The blood is to be examined in 3 thick drop specimens and one thin film.

Date	26	27	28	29	30	31	1st Sep	2	3	4	5	6	7	8	9	10	11
Day of treatment	Before the treatment	1st day of treatment	2nd day	3rd day	4th day	5th day	6th day	7th day	8th day			11th day	12th day	13th day	14th day	15th day	
Rings	+								—			—				—	
Schizonts	—								—			—				—	
Gametocytes	—								+			—				—	
Temperature	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E	M E



Spleen Twofingers enlarged.	+															—	
Medicaments employed and its dose																	

Toxic Symptoms: Specify date of onset and duration

	Before treatment	During treatment
1. Albuminuria		
2. Skin discoloration		
3. Cyanosis		
4. Diarrhoea		
5. Cerebral Excitation		
6. Gastralgia		
7. Haemoglobinuria		
8. Cardiac Troubles		
9. Nausea		
10. Vomiting		
11. Vertigo		+ 6th to 9th sept 1935
12. Other symptoms		

0.375 gm. atebrin musonat in 9 c.c. of distilled water injected; plasmoquin tablets 0.02 gm., t.d.s. for five days, starting on 3rd September, 1935.

The effect on fever and parasites in blood was equally good. The patients felt quite well on the day after the injection, and, if they had not been needed for our observations, appeared fit to be discharged from hospital on that day. However, we do not wish to recommend such an early discharge, because clinical experience has proved that the 'defence forces' of the body certainly act better under conditions of complete rest in bed than under conditions of muscular and general activity. The latter necessitates a higher metabolic activity mainly supplied by the glycogen depôts of the liver. The method appears convenient for the patients because of necessitating one injection only. They could safely be discharged on the day on which the peroral treatment is concluded. For practical purposes it may be possible to discharge the patient on the second or third 'peroral' atebrin day, recommend him for light duty, and declare him fit after three to four subsequent days in accordance with the results of blood examination.

That the physiological effects of adrenaline enhance the therapeutic action of atebrin musonate is possible, but the evidence is not conclusive.

In respect of the practical success, it can safely be stated that method I gave the best results. No clinical or parasitological relapses were detected after the commencement of treatment.

Method III gave the next best results. Only one clinical and one parasitological relapse was observed.

Method II furnished unsatisfactory results. Both clinical and parasitological relapses were more frequent than in Series III. It appears that the dosage of 0·375 gm. atebrin musonate, although combined with adrenaline, is not sufficient.

It may be stated, therefore, that method I appears to be the safest, most reliable and convenient treatment for restoring the fitness of our patients for military duty by the administration of atebrin and atebrin musonate.

REFERENCE.

BLAZE, J. R., and SIMEONS, A. T. W. (1935). Preliminary Observations on a New Soluble Atebrin Compound. *Ind. Med. Gaz.*, **70**, 4, pp. 185-188.

Records of the Malaria Survey of India, **6**, 2, *June*, 1936.

THE DISTRIBUTION OF ANOPHELINE MOSQUITOES IN INDIA : ADDITIONAL RECORDS,* 1931—1935.

BY

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(*Indian Research Fund Association.*)

[17th February, 1936.]

THE records of the distribution of the anopheline mosquitoes of India and Ceylon were first summarized by Covell in a memoir published in 1927†. This included all discoverable records up to the middle of 1926. The same author (Covell, 1931)† published, subsequently, a supplement to this *Memoir*, giving additional information recorded up to the end of 1930. Barraud (1933)† has again supplemented this information, giving, however, only those *new* data of species recorded in the identification registers of the Central Malaria Bureau in the course of routine examinations made up to 15th April, 1933. Since the publication of the last two papers (Covell, 1931 and Barraud, 1933), a number of additional records have been received by the Malaria Survey of India, or have appeared in the various published or MS. reports of mosquito surveys in different parts of India. In the present paper an attempt has been made to include all *new* records received since the latter papers were published, also other ones which had been overlooked in the previous works. This includes records up to the end of 1935. The data from which these have been drawn consist of the identification records of the Malaria Survey of India, published works, MSS. or other reports received from various provinces, and which are filed in the library of the Malaria Survey of India.

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* This paper may be considered as the third supplement to the *Ind. Med. Res. Mem.* No. 5.

† Barraud, P. J. (1933), 'Additional Records of the Distribution of Anopheline Mosquitoes in India (from January 1, 1931 to April 15, 1933)'. *Rec. Mal. Surv. Ind.*, **3**, 3, pp. 507–525.

Covell, G. (1927), 'The Distribution of Anopheline Mosquitoes in India and Ceylon'. *Ind. Med. Res. Mem.* No. 5.

Covell, G. (1931), 'The Distribution of Anopheline Mosquitoes in India and Ceylon: Additional Records, 1926–1930'. *Rec. Mal. Surv. Ind.*, **2**, 2, pp. 225–268.

As in the previous two 'additional records' of distribution (Covell, 1931, and Barraud, 1933), only *new* records have been given here. In cases where a species has already been cited in any of the previous papers on geographical distribution, as occurring in any particular locality, additional records of that species from the same place have not been included here. However, if a species has been cited as occurring in a district without the name of any particular area, records of such species from definite localities in that district have been cited.

The species of anophelines, and the geographical divisions, subdivisions and localities from which they have been recorded, have been given in alphabetical order. Figures preceded by the letters *MB.* refer to entries in the identification registers of the Central Malaria Bureau, Malaria Survey of India, Kasauli. All other figures refer to the reports and articles cited in the list of references at the end of the paper, and these have been serially numbered in continuation of those given by Covell (1927) in his original memoir and in his supplementary paper (Covell, 1931).

aconitus.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.**, Chardaur, **179c,** Lokra, **179c,** Mangaldai, **182a,** Tezpur, **179d; Garo Hills Dist.**, Tura, **179g; Goalpara Dist.**, Abhayapuri, **MB. 129-33,** Dhubri, **182a; Lakhimpur Dist.**, North Lakhimpur, **182a; Nowgong Dist.**, Dimapur, **182a,** Nowgong, **MB. 161-33; Sibsagar Dist.**, Golaghat, **MB. 9-35,** Jorhat, **175; Sylhet Dist.**, Amo T. E., **187,** Begum Khan T. E., **187,** Nijpat Jaintiapur, **162a,** Teliapara T. E., **187.**

BENGAL.

Birbhum Dist., Bolpur, **191; Chittagong Dist.**, Pahartoli, **182a; Noakhali Dist.**, Chhagatnaia, **181,** Ijjatpur, **181,** Matua, **181,** Rahamatpur, **181; Rangpur Dist.**, Saidpur, **157b; 24-Parganas Dist.**, Sitola, **184,** Sonarpur, **184,** Ukhila, **184.**

HYDERABAD SOUTH.

Atraf-i-Balada Dist., Ramkote, **157b.**

MADRAS COAST NORTH.

Vizagapatam Dist., Chitikona Summit, **MB. 283-33.**

MYSORE STATE.

Mysore Dist., Mysore, **178c,** Nagoonhalli, **178f.**

ORISSA.

Balasore Dist., Balasore, **157b,** Bhadrak, **154a; Puri Dist.**, Khurda Road, **180.**

aitkeni.

ASSAM.

Darrang Dist., Chardaur, **179c,** Lokra, **179c; Kamrup Dist.**, Gauhati, **182a; Sibsagar Dist.**, Jorhat, **175.**

BENGAL.

Jalpaiguri Dist., Binaguri, **MB. 33-35,** Samsing, **165a.**

BURMA UPPER.

Mandalay Dist., Maymyo, **161c.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **MB. 61-34.**

MALABAR.

Coorg Province, Fraserpet, **169b,** Gonicoppal, **170c,** Sampaje, **169c,** Suntikoppa, **169b.**

aitkeni var. **bengalensis.**

ASSAM.

Cachar Dist., Haflong, **183b; Darrang Dist.,** Chardaur, **179c,** Lokra, **179c; Garo Hills Dist.,** Tura, **179g; Lakhimpur Dist.,** Pasighat, **179b.**

BENGAL.

Darjeeling Dist., Kalimpong, **188,** Melli, **188,** Mungpo, **188,** Simlay, **188,** Soriang, **188.**

SIKKIM.

Gangtok, **188,** Reshob, **188.**

annularis.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **MB. 107-33,** Lokra, **179c,** Mangaldai, **182a,** Tezpur, **182a; Garo Hills Dist., 185,** Tura, **179g; Goalpara Dist.,** Abhayapuri, **MB. 115-33,** Dhubri, **182a; Lakhimpur Dist.,** Bordubi, **182a,** Namsang, **182a,** North Lakhimpur, **182a; Manipur State,** Imphal, **MB. 177-33; Nowgong Dist.,** Dimapur, **182a; Sibsagar Dist.,** Borpatra (Nr. Borhat), **183a,** Jorhat, **175; Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

BENGAL.

Birbhum Dist., Bholpur, **191; Calcutta,** Garden Reach, **159a,** Salt Lakes, **165b; Chittagong Dist.,** Pahartoli, **182a,** Rangamatti, **165a; Darjeeling Dist.,** Sukna, **165a; Howrah Dist.,** Lillooah, **MB. 170-33; Jalpaiguri Dist.,** Madarihat, **165a; Noakhali Dist.,** Chanandi, **181,** Char Banda, **181,** Char Bata, **181,** Char Iswar Ray, **181,** Chhagatnaia, **181,** Chitra Khali, **181,** Dublafar, **181,** Ijjatpur, **181,** Kalapani, **181,** Matua, **181,** Nalchira, **181; 24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173; Sholapur Dist.,** Ashti, **173,** Babhulgaon, **173,** Kuslamb, **173,** Pandharpur, **173,** Ramling, **173,** Yedsi, **173.**

CENTRAL INDIA WEST.

Bhopal State, Bhopal, **MB. 189-34.**

CENTRAL PROVINCES WEST.

Nagpur Dist., Kamptee, **MB. 28-35.**

CHOTA NAGPUR.

Palamau Dist., Barwadih, **MB. 147-33; Singhbhum Dist.,** Noamundi, **186.**

GUJRAT.

Kaira Dist., Bherai, **MB. 187-34,** Chalindra, **MB. 188-34,** Dhathal, **MB. 187-34,** Navagana, **MB. 179-34,** Nayaka, **MB. 179-34,** Pangoli, **MB. 187-34,** Pinglaj, **MB. 187-34,** Wadala, **MB. 187-34; Panch Mahals Dist.,** Freelandganj, **MB. 229-33; Surat Dist.,** Ashtagam, **MB. 282-33,** Bansda, **MB. 115-34,** Lawachha, **MB. 282-33,** Supa, **MB. 282-33.**

HYDERABAD NORTH.

Osmanabad Dist., Murud, **173,** Neoli, **173.**

KONKAN.

North Kanara Dist., Bhendigiri, **MB. 49-34,** Kundayi, **MB. 49-34,** Shirnal, **MB. 64-34; Thana Dist.,** Thana, **MB. 290-33.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Mercara, **169a,** Ponampet, **170c,** Sampaje, **169c,** Verajpet, **192.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178c,** Nagoonhalli, **178f.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Patna State,** Villages along the Kantabhanji-Sonepur projected railway line, **154b; Puri Dist.,** Khurda Road, **180.**

PUNJAB EAST AND NORTH.

Hissar Dist., Sirsa, **MB. 149-34; Patiala State,** Bhawanigarh, **159b,** Chuharpur Mirasian, **159b,** Dadhera, **159b,** Kalyan, **159b,** Mador, **159b.**

RAJPUTANA WEST.

Bikaner State, Bijhey Bhawan, **174,** Gajner, **174,** Lallgarh, **174; Sirohi State,** Achhalgarh, **MB. 184-33,** Delwara, **MB. 184-33,** Dhundai, **MB. 184-33,**

Goa Gaon, **MB. 184-33,** Gora Chhapra, **MB. 184-33,** Hetamji, **MB. 184-33,** Jawai, **MB. 184-33,** Kalachhapra, **MB. 184-33,** Kumharwara, **MB. 184-33,** Moch, **MB. 184-33,** Oria, **MB. 184-33,** Salgaon, **MB. 184-33,** Torna, **MB. 184-33.**

SIKKIM.

Khaingaon, **188,** Rungo, **188,** Sichygong, **188,** Tadong, **188.**

SIND.

Karachi Dist., Daro, **160d,** Mirpur Bathoro, **160d.**

barbirostris.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **179c,** Lokra, **179c,** Mangaldai, **182a,** Tezpur, **182a; Garo Hills Dist.,** Tura, **179g; Goalpara Dist.,** Abhayapuri, **MB. 129-33,** Dhubri, **182a; Manipur State,** Imphal, **MB. 151-35; Khasi and Jaintia Hills Dist.,** Nongpoh, **182a; Lakhimpur Dist.,** Bordubi, **182a,** North Lakhimpur, **182a; Nowgong Dist.,** Dimapur, **182a; Sibsagar Dist.,** Jorhat, **175,** Borpatra (Nr. Borhat), **183a; Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

BENGAL.

Birbhum Dist., Bolpur, **191; Calcutta,** Garden Reach, **159a,** Salt Lakes, **165b; Chittagong Dist.,** Pahartoli, **182a; Darjeeling Dist.,** Sukna, **165a; Noakhali Dist.,** Chanandi, **181,** Char Banda, **181,** Char Bata, **181,** Char Iswar Ray, **181,** Char Lakhmi, **181,** Chhagatnaia, **181,** Chitra Khali, **181,** Dublafar, **181,** Ijjatpur, **181,** Kalapani, **181,** Matua, **181,** Musapur, **181,** Nalchira, **181,** Rahmatpur, **181,** Sandwip Town (Harishpur), **181; 24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BOMBAY DECCAN.

Kolhapur State, Sulgare, **173; Sholapur Dist.,** Bohali, **173,** Kalamb Road, **173,** Kuslamb, **173.**

BURMA UPPER.

Myitkyina Dist., Sahmaw, **161a.**

CENTRAL INDIA WEST.

Bhopal State, Bhopal, **MB. 193-34.**

CENTRAL PROVINCES WEST.

Jubbulpur Dist., Jubbulpore, **MB. 82-33.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

GUJRAT.

Baroda State, Baroda, **MB. 1-35.**

HYDERABAD NORTH.

Osmanabad Dist., Hangul, **173**, Palsap, **173.**

HYDERABAD SOUTH.

Atraf-i-Balda Dist., Hyderabad, **149.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Fraserpet, **169b,** Gonicoppal, **170a,** Mercara, **169a,** Ponampet, **170c,** Sampaje, **169d,** Somwarpet, **169b,** Srimangala, **170a,** Suntikoppa, **169b,** Virajpet, **169a.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.**, Mysore, **178e,** Nagoonhalli, **178f.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Puri Dist.**, Khurda Road, **180.**

barbirostris var. **ahomi.**

ASSAM.

Darrang Dist., Chardaur, **179c,** Lokra, **179c; Lakhimpur Dist.**, North Lakhimpur, **182a.**

culicifacies.

ASSAM.

Cachar Dist., Hailakandi, **182a,** Haflong, **183b; Darrang Dist.**, Chardaur, **MB. 107-33,** Lokra, **179c,** Mangaldai, **179a,** Tezpur, **182a; Garo Hills Dist.**, Tura, **179g; Goalpara Dist.**, Abhayapuri, **MB. 115-33,** Dhubri, **182a,** Kachugaon, **163a; Kamrup Dist.**, Gauhati, **182a; Khasi and Jaintia Hills Dist.**, Nongpoh, **182a; Lakhimpur Dist.**, Bordubi, **182a;** North Lakhimpur, **179h,** Pasighat, **179b; Manipur State,** Imphal, **MB. 177-33; Sibsagar Dist.**, Jorhat, **175; Sylhet Dist.**, Amo T. E., **187,** Begum Khan T. E., **187,** Nijpat Jaintiapur, **162a,** Teliapara T. E., **187.**

BALUCHISTAN.

Zhob Dist., Gulkach, **MB. 69-34,** Hindubagh, **MB. 118-35.**

BENGAL.

Birbhum Dist., Bolpur, **191; Calcutta,** Garden Reach, **159a; Chittagong Dist.**, Pahartoli, **182a; Darjeeling Dist.**, Sindipung, **188; 24-Parganas Dist.**, Sitola, **184,** Ukhila, **184.**

BIHAR.

Patna Dist., Patna, **151.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173,** Athni Road, **173; Kolhapur State,** Bolwad, **173,** Dhalgaon, **173,** Dhulgaon, **173,** Gulvanchi, **173,** Kavathe Mahankal, **173,** Langerpeth, **173,** Miraj, **173,** Sulgare, **173; Poona Dist.,** Dhairi, **MB. 126-33,** Dhankodi, **MB. 126-33,** Hingne, **MB. 126-33,** Khadakwasala, **MB. 126-33,** Kirkatwadi, **MB. 126-33,** Kotrud, **MB. 126-33,** Nahra, **MB. 126-33,** Nanded, **MB. 126-33,** Parvati, **MB. 126-33,** Vadgaon, **MB. 126-33,** Vithalwadi, **MB. 126-33,** Warji, **MB. 126-33,** Yerandavne, **MB. 126-33; Sholapur Dist.,** Ashti, **173,** Babhulgaon, **173,** Bamani, **173,** Barsi Town, **173,** Bohali, **173,** Chink Hill, **173,** Jath Road, **173,** Javla, **173,** Kalamb Road, **173,** Kuslamb, **173,** Laul, **173,** Mahisgaon, **173,** Modlimb, **173,** Padsali, **173,** Pandharpur, **173,** Pangri, **173,** Ramling, **173,** Sangola, **173,** Shendri, **173,** Uplai **173,** Wasud, **173,** Yedsi, **173.**

BURMA UPPER.

Magwe Dist., Taungkanyo, **MB. 218-33,** Theingone, **MB. 218-33.**

CENTRAL INDIA WEST.

Bhopal State, Bhopal, **MB. 193-34.**

GUJRAT.

Surat Dist., Bansda, **MB. 102-34,** Lawatchha, **MB. 282-33,** Mandvi, **MB. 274-33,** Satan, **MB. 279-33.**

HYDERABAD NORTH.

Osmanabad Dist., Dhoki, **173,** Hangul, **173,** Latur, **173,** Murud, **173,** Neoli, **173,** Owasa Road, **173,** Palsap, **173,** Thair, **173.**

HYDERABAD SOUTH.

Atraf-i-Balda Dist., Trimulgerry, **MB. 125-35.**

KONKAN.

Goa, Satary, **MB. 37-34; North Kanara Dist.,** Bhendigiri, **MB. 49-34,** Somnalli, **MB. 49-34; Thana Dist.,** Bhira (Andhra Valley), **MB. 79-33,** Thana, **MB. 272-33.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Fraserpet, **169a,** Gonicoppal, **170a,** Mercara, **192,** Sampaje, **169c,** Siddapur, **170b,** Somwarpet, **169b,** Srimangala, **170b,** Suntikoppa, **169b,** Tittimatti, **170f; Travancore State,** Kulesekharam, **165c.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Kolar Dist.,** Kamadanahalli, **190; Mysore Dist.,** Hulikere Tunnel Works, **190,** Mysore, **178c,** Nagoonhalli, **178f.**

NORTH-WEST FRONTIER PROVINCE.

Mohmands Territory, Galanai, **MB. 207-33.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Patna State,** Villages along Kantabhanji-Sonepur projected railway line, **154b; Puri Dist.,** Khurda Road, **180.**

PUNJAB EAST AND NORTH.

Hissar Dist., Sirsa, **MB. 129-34; Jullundur Dist., MB. 44-34; Patiala State,** Bhawanigarh, **159b,** Chuharpur Mirasian, **159b,** Dadhera, **159b,** Kalayan, **159b,** Patiala, **159b.**

RAJPUTANA EAST.

Jaipur State, Sambhar, **MB. 78-32.**

RAJPUTANA WEST.

Bikaner State, Bijhey Bhawan, **174,** Gajner, **174,** Lallgarh, **174; Sirohi State,** Achhalgarh, **MB. 184-33,** Delwara, **MB. 184-33,** Dhundai, **MB. 184-33,** Goa Gaon, **MB. 184-33,** Gora Chhapra, **MB. 184-33,** Hetamji, **MB. 184-33,** Jawai, **MB. 184-33,** Kala Chhapra, **MB. 184-33,** Kumharwara, **MB. 184-33,** Moch, **MB. 184-33,** Oria, **MB. 184-33,** Salgaon, **MB. 184-33,** Torna, **MB. 184-33.**

SIKKIM.

Rungo, **188.**

SIND.

Dadu Dist., Dadu, **160f,** Pir Gazi Shah, **160f; Hyderabad Dist.,** Hala, **160i; Karachi Dist.,** Bano, **160d,** Belo, **160d,** Bhero Sumro, **160d,** Bhati, **160d,** Chang, **160d,** Churetani, **160d,** Daho, **160d,** Dari, **160d,** Daro, **160d,** Geduro, **160d,** Habib Mullah, **160d,** Haider Ali Shah, **160d,** Joakh, **160d,** Kandri, **160d,** Ladiun, **160d,** Mirpur Bathoro, **160d,** Mirzo Laghari, **160d,** Mughulbhin, **160d,** Mullah, **160d,** Patori, **160d,** Pir Karim Shah, **160d,** Sando Bandar, **160d,** Shahbandar, **160d,** Sidik Shora, **160d,** Sujawal, **160d,** Tal, **160d; Khairpur State,** Baharo Khan Lashari, **160h,** Fatehpur, **160h,** Gambat, **160h,** Khairpur, **160h,** Kohora, **160h,** Lukman, **160h,** Paneroo, **160h,** Tando Mastikhan, **160h; Larkana Dist.,** Berochandia, **193,** Bher, **193,** Dodai, **193,** Dokri, **193,** Ghari Khuda Baksh, **160g,** Kambar, **193,** Masu Dero, **160g,** Miro Khan, **160g,** Naundero, **193,** Nao Dero, **160g,** Nasirabad, **160g,** Panjoo Dero, **160g,** Pir Baksh Bhuto, **160g,** Pir Jo Got, **160g,** Ratodero, **160g,** Tharo Wadho, **160g,** Warah, **160g; Nawabshah Dist.,** Abji, **160a,** Bhiria, **160a,** Dehran, **160a,** Kazi Ahmed, **160a,** Mari, **160a,** Miani, **160a,** Nawazdhari, **160a,** Sadhuja, **160a,** Sarhari, **160a; Sukkur Dist.,** Bagarji, **160e,** Bichanji, **160e,** Dodogot, **160e,** Jahan Khan, **160e,** Miani Bhagat, **160e,** Pano Akil, **160e,** Pitafi, **160e,** Shahpur, **160e; Upper Sind Frontier Dist.,** Bhalaindina Abad, **160c,** Chana, **160c,** Dakhan, **160c,** Dari, **160c,** Dil Murad Koso, **160c,** Gauspur, **160c,** Gurhi Hassan, **160c,** Hayabat, **160c,** Imam Baksh, **160c,** Jiand Jarwar, **160c,** Kandhkot, **160c,** Kashmor, **160c,** Maulabad, **160c,** Mirpur, **160c,** Murad Koso, **160c,** Ramzanpur, **160c,** Thul, **160c.**

UNITED PROVINCES EAST.

Allahabad Dist., Allahabad, **MB. 357-31; Gorakhpur Dist.,** Gorakhpur, **MB. 195-35.**

dthali.

BALUCHISTAN.

Loralai Dist., Loralai, **MB. 195-33.**

fluviatilis.

ASSAM.

Cachar Dist., Labac, **MB. 13-34; Garo Hills Dist.,** Tura, **MB. 58-34; Goalpara Dist.,** Abhayapuri, **MB. 11-34,** Kachugaon, **163a; Lakhimpur Dist.,** Doom Dooma, **182a.**

BENGAL.

Jalpaiguri Dist., Sylee, **171; Nadia Dist.,** Krishnagar, **152.**

BIHAR.

Gaya Dist., Gaya, **MB. 212-34.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173,** Athni Road, **173; Kolhapur State,** Dhulgaon, **173,** Kavathe Mahankal, **173,** Langerpeth, **173,** Sulgare, **173; Poona Dist.,** Dhairi, **MB. 236-33,** Hingne, **MB. 22-33,** Kothrud, **MB. 200-33,** Nahra, **MB. 126-33,** Poona, **MB. 5-35,** Vadgaon, **MB. 200-33,** Vithalwadi, **MB. 200-33; Sholapur Dist.,** Bohali, **173,** Chink Hill, **173,** Kalamb Road, **173,** Kuslamb, **173,** Padsali, **173,** Pandharpur, **173,** Ramling, **173,** Yedsi, **173.**

BURMA UPPER.

Hsipaw State (N. Shan States), Kalwa, **157b.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

HYDERABAD NORTH.

Osmanabad Dist., Hangul, **173,** Latur, **173,** Murud, **173,** Neoli, **173,** Palsap, **173.**

KASHMIR.

Tangmarg, **157b.**

KONKAN.

Goa, Old Goa, **MB. 37-34; Thana Dist.,** Andhara Valley, **157b.**

MADRAS DECCAN.

Bellary Dist., Sandur State, **157b.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Gonicoppal, **170a,** Kanur, **170e,** Nagarahole, **170d,** Ponampet, **170a,** Sampaje, **169c,** Siddapur, **170a,** Suntikoppa, **169a; Travancore State,** Kulesekharam, **165c.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178c,** Nagoonhalli, **178f.**

NORTH-WEST FRONTIER PROVINCE.

Peshawar Dist., Bargholi (Mardan), **MB. 63-35.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Kalahandi State,** Kakbhata, **MB. 6-34.**

PUNJAB EAST AND NORTH.

Ambala Dist., Ambala, **MB. 163-33.**

RAJPUTANA EAST.

Ajmer-Merwara Province, Nasirabad, **MB. 186-35.**

RAJPUTANA WEST.

Sirohi State, Delwara, **MB. 184-33,** Dhundai, **MB. 184-33,** Goa Gaon, **MB. 184-33,** Gora Chhapra, **MB. 184-33,** Hetamji, **MB. 184-33,** Kala Chhapra, **MB. 184-33,** Kumharwara, **MB. 184-33,** Jawai, **MB. 184-33,** Mach, **MB. 184-33,** Oria, **MB. 184-33,** Salgaon, **MB. 184-33,** Torna, **MB. 184-33.**

UNITED PROVINCES WEST.

Moradabad Dist., Moradabad, **MB. 204-34.**

WAZIRISTAN.

Derajat Area, Jandola, **157b,** Sarwakai, **157b.**

gigas.

ASSAM*.

Goalpara Dist., Dhubri, **182a,** Kachugaon, **163b; Kamrup Dist., 182b,** Gauhati, **182a; Lakhimpur Dist.,** North Lakhimpur, **182a; Naga Hills Dist.,** Kohima, **182a; Nowgong Dist., 182b; Sibsagar Dist.,** Jorhat, **175.**

SIKKIM*.

Gangtok, **188.**

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* These records most probably refer either to *gigas* var. *baileyi* or to var. *simlensis*.

MALABAR.

Coorg Province, Gonicoppal, **170c,** Ponampet, **170c.**

gigas var. **baileyi.**

ASSAM.

Cachar Dist., Labac, **157a; Garo Hills Dist.,** Tura, **179g; Goalpara Dist.,** Abhayapuri, **MB. 11-34; Khasi and Jaintia Hills Dist.,** Dumpep, **157a; Lakhimpur Dist.,** Doom Dooma, **157a.**

BENGAL.

Rangpur Dist., Saidpur, **157a.**

BURMA UPPER.

Hsipaw State (N. Shan States), Kalaw, **157a.**

gigas var. **simlensis.**

ASSAM.

Lakhimpur Dist., Pasighat, **179b.**

KASHMIR.

Aran, **157a,** Nara Nag, **157a.**

UNITED PROVINCES WEST.

Moradabad Dist., Moradabad, **MB. 7-35.**

habibi*.

BALUCHISTAN.

Quetta-Pishin, Quetta, Hudda.

hyrcanus var. **nigerrimus.**

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **179c,** Lokra, **179c,** Mangaldai, **182a; Garo Hills Dist., 185; Goalpara Dist.,** Abhayapuri, **MB. 129-33,** Dhubri, **182a; Lakhimpur Dist.,** Bordubi, **182a,** Namsang, **182a,** North Lakhimpur, **182a; Manipur State,** Imphal, **MB. 177-33; Nowgong Dist.,** Dimapur, **182a; Sibsagar Dist.,** Borpatra T. E. (Nr. Borhat), **183a,** Jorhat, **175; Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

BENGAL.

Calcutta, Garden Reach, **159a,** Salt Lakes, **165b; Chittagong Dist.,** Pahartoli, **182a; Howrah Dist.,** Lillooah, **MB. 170-33; Noakhali Dist.,**

* These specimens were collected during the Malaria Survey of Quetta, in August-September, 1935, and are being described as a new species by Mulligan and Puri, in a paper appearing in *Records of the Malaria Survey of India,* Vol. VI, No. 1, 1936.

Chanandi, **181,** Char Banda, **181,** Char Bata, **181,** Chhagatnaia, **181,** Ijjatpur, **181,** Kalapani, **181,** Matua, **181,** Rahamatpur, **181; 24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BIHAR.

Patna Dist., Patna, **151.**

BOMBAY DECCAN.

Kolhapur State, Kavathe Mahankal, **173; Sholapur Dist.,** Ashti, **173,** Bohali, **173,** Chink Hill, **173,** Pandharpur, **173,** Sangola, **173.**

CENTRAL INDIA WEST.

Bhopal State, Bhopal, **MB. 199-34.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

HYDERABAD NORTH.

Osmanabad Dist., Hangul, **173,** Owasa Road, **173,** Palsap, **173.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Fraserpet, **169b,** Gonicoppal, **170a,** Kanur, **170e,** Nagarahole, **170d,** Ponampet, **170c,** Sampaje, **169c,** Somwarpet, **169b,** Suntikoppa, **169b.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178c,** Nagoonhalli, **178f.**

NORTH-WEST FRONTIER PROVINCE.

Swat Territory, Chakdara, **MB. 223-33.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Puri Dist.,** Khurda Road, **180.**

PUNJAB EAST AND NORTH.

Gujranwala Dist., Chichoki Malian, **MB. 71-35; Sialkot Dist.,** Sialkot, **MB. 167-33; Ambala Dist.,** Ambala, **MB. 163-33.**

SIND.

Larkana Dist., Kambar, **160g,** Tharo Wadho, **160g.**

SIKKIM.

Rungo, **188,** Sington, **188.**

UNITED PROVINCES WEST.

Muttra Dist., Muttra, **MB. 197-33.**

hyrcanus var. **sinensis.**

ASSAM.

Manipur State, Ukhrul, **157a.**

BURMA UPPER.

Hsipaw State (N. Shan States), Kalwa, **157a; North Hsenwi State** (N. Shan States), Namtu, **157a.**

insulæflorum.

ASSAM.

Darrang Dist., Chardaur, **179c,** Lokra, **179c; Kamrup Dist.,** Gauhati, **179e; Lakhimpur Dist.,** Pasighat, **179b.**

MYSORE STATE.

Kadur Dist., Mudigere, **178d.**

jamesi.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Mangaldai, **179a,** Tezpur, **179d; Kamrup Dist.,** Gauhati, **179f; Sylhet Dist.,** Haripur, **MB. 82-34,** Nijpat Jaintiapur, **162a.**

BENGAL.

Birbhum Dist., Bolpur, **191; Chittagong Dist.,** Rangamatti, **165a; 24-Parganas Dist.,** Port Canning, **156*.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173; Sholapur Dist.,** Bohali, **173,** Yedsi, **173.**

CENTRAL INDIA WEST.

Bhopal State, Bhopal, **MB. 189-34.**

CHOTA NAGPUR.

Singhbhum Dist., Dangoaposi, **MB. 287-33,** Noamundi, **186.**

GUJRAT.

Surat Dist., Bansda, **MB. 115-34.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

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* Identification doubtful; may have been *ramsayi*.

MALABAR.

Coorg Province, Somwarpet, **169d,** Suntikoppa, **169d.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178c,** Nagoonhalli, **178f.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Puri Dist.,** Khurda Road, **180.**

RAJPUTANA WEST.

Sirohi State, Delwara, **MB. 184-33,** Jawai, **MB. 184-33,** Mount Abu, **167.**

jeyporiensis.

ASSAM.

Darrang Dist., Chardaur, **179c,** Lokra, **179c,** Tezpur, **182a; Kamrup Dist.,** Gauhati, **MB. 206-34; Khasi and Jaintia Hills Dist.,** Umran, **182a; Lakhimpur Dist.,** Pasighat, **179b; Nowgong Dist., 182b,** Dimapur, **182a; Sibsagar Dist.,** Jorhat, **175.**

BENGAL.

Jalpaiguri Dist., Dalinkote (Nr. Meenglas), **172,** Sylee, **171.**

BOMBAY DECCAN.

Poona Dist., Dhairi, **MB. 236-33.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

HYDERABAD SOUTH.

Atraf-i-Balda Dist., Trimulgerry, **MB. 36-35.**

KONKAN.

North Kanara Dist., Badralli, **MB. 64-34,** Balgar, **MB. 25-34,** Hansangaddi, **MB. 64-34,** Hitlalli, **MB. 49-34,** Hutkhand, **MB. 49-34,** Kalchi, **MB. 64-34,** Malalgaon, **MB. 49-34,** Yellapur, **MB. 293-33.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Fraserpet, **169a,** Gonicoppal, **170a,** Hallery, **192,** Nagarahole, **170d,** Ponampet, **170a,** Sampaje, **169c,** Siddapur, **170a,** Suntikoppa, **169a,** Tittimatti, **170f; Travancore State,** Kulesekharam, **165c.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178e,** Nagoonhalli, **178f.**

jeyporiensis var. **candidiensis.**

ASSAM.

Cachar Dist., Labac, **157a; Khasi and Jaintia Hills Dist.,** Nongpoh, **157a,** Shillong, **157a.**

BENGAL.

Jalpaiguri Dist., Rangamatti, **157a.**

BURMA UPPER.

Mandalay Dist., Maymyo, **MB. 216-30.**

UNITED PROVINCES WEST.

Nainital Dist., Kichha, **157a.**

MALABAR.

Travancore State, Kulesekharam, **165d.**

karwari.

ASSAM.

Garo Hills Dist., Tura, **179g; Sibsagar Dist.,** Jorhat, **175; Sylhet Dist.,** Haripur, **MB. 82-34,** Nijpat Jaintiapur, **162a.**

BENGAL.

Birbhum Dist., Bolpur, **191; Chittagong Dist.,** Rangamatti, **165a.**

BOMBAY DECCAN.

Sholapur Dist., Kurduvadi, **173.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

MADRAS COAST NORTH.

Vizagapatam Dist., Chitikona, **MB. 166-35.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Fraserpet, **169c,** Gonicoppal, **170a,** Sampaje, **169c,** Siddapur, **170a,** Somwarpet, **169b,** Suntikoppa, **169a,** Virajpet, **192.**

MYSORE STATE.

Mysore Dist., Nagenhalli, **178e.**

ORISSA.

Balasore Dist., Bhadrak, **MB. 283-33; Puri Dist.,** Khurda Road, **180.**

kochi.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **179c,** Lokra, **179c,** Tezpur, **182a; Garo Hills Dist.,** Tura, **179g; Goalpara Dist.,** Abhayapuri, **MB. 210-33,** Dhubri, **182a; Lakhimpur Dist.,** Digboi, **MB. 161-33,** North Lakhimpur, **179h; Nowgong Dist.,** Dimapur, **182a; Sibsagar Dist.,** Borpatra T. E. (Nr. Borhat), **183a,** Jorhat, **175; Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

leucosphyrus.

ASSAM.

Garo Hills Dist., Tura, **179g; Sibsagar Dist.,** Jorhat, **175; Sylhet Dist.,** Nijpat Jaintiapur, **162a,** Sylhet, **MB. 68-34.**

BENGAL.

Darjeeling Dist., Sukna, **165a; Jalpaiguri Dist.,** Dalgaon, **MB. 294-33,** Madarihat, **165a.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **MB. 61-34.**

MALABAR.

Coorg Province, Gonicoppal, **170c,** Somwarpet, **169c.**

lindesayi.

ASSAM.

Garo Hills Dist., Tura, **179g.**

BENGAL.

Darjeeling Dist., Dungra, **188,** Kalimpong, **188; Jalpaiguri Dist.,** Sam Sing, **165a.**

NORTH-WEST FRONTIER PROVINCE.

Peshawar Dist., Dargai, **MB. 240-33.**

maculatus*.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **179c,** Lokra, **179c,** Tezpur, **182a; Garo Hills Dist.,** Tura, **179g; Khasi and Jaintia Hills Dist.,** Umran, **182a; Lakhimpur Dist.,** North Lakhimpur, **182a; Nowgong Dist.,** Dimapur, **182a; Sibsagar Dist.,** Jorhat, **175; Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

BENGAL.

Chittagong Dist., Pahartoli, **182a; Darjeeling Dist.,** Chibe, **188,** Dungra, **188,** Giellekhella, **188,** Kalimpong, **188,** Mangwa, **188,** Melli, **188,** Mungpo,

* A number of these records refer most probably to var. *willmori.*

188, Simlay, **188,** Sindipung, **188,** Soriang, **188,** Tista Bazar, **188; Jalpaiguri Dist.,** Raja Bhat Khawa, **165a.**

BIHAR.

Gaya Dist., Gaya, **MB. 20-35.**

BOMBAY DECCAN.

Belgaum Dist., Athni Road, **173; Sholapur Dist.,** Kalamb Road, **173,** Kurduvadi, **173,** Laul, **173,** Mahisgaon, **173,** Pangri, **173,** Ramling, **173.**

BURMA UPPER.

Mandalay Dist., Maymyo, **161c.**

CHOTA NAGPUR.

Palamau Dist., Barwadih, **MB. 43-35.**

HYDERABAD NORTH.

Osmanabad Dist., Hangul, **173,** Latur, **173,** Palsap, **173.**

KONKAN.

Thana Dist., Bhira (Andhra Valley), **MB. 79-33.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MYSORE STATE.

Bangalore Dist., Bangalore, **178d.**

NORTH-WEST FRONTIER PROVINCE.

Mohmands Territory, Galanai, **MB. 207-33.**

SIKKIM.

Duga, **188,** Gangtok, **188,** Majhitar, **188,** Momriang, **188,** Reshob, **188,** Rungo, **188,** Sankakhola, **188,** Sichyong, **188,** Sington, **188,** Tadong, **188.**

maculatus var. **willmori.**

ASSAM.

Garo Hills Dist., Tura, **179g.**

BENGAL.

Darjeeling Dist., Chibe, **188,** Dungra, **188,** Kalimpong, **188,** Sindipung, **188,** Tarkhola, **188.**

SIKKIM.

Duga, **188,** Gangtok, **188,** Majhitar, **188,** Rungo, **188,** Sichygong, **188.**

WAZIRISTAN.

Bannu Area, Mir Ali, **MB. 96-33.**

majidi.

ASSAM.

Cachar Dist., Labac, **MB. 203-33.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

MADRAS COAST NORTH.

Vizagapatam Dist., Bariguda (Jeypore Hills), **MB. 37-35.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Somwarpet, **169c.**

minimus.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **179c,** Lokra, **179c,** Mangaldai, **182a,** Tezpur, **179d; Garo Hills Dist.,** Tura, **179g; Goalpara Dist.,** Abhayapuri, **MB. 166-33,** Dhubri, **182a; Khasi and Jaintia Hills Dist.,** Umran, **182a; Lakhimpur Dist.,** Bordubi, **182a,** North Lakhimpur, **182a,** Pasighat, **179b; Nowgong Dist.,** Dimapur, **182a,** Solana, **157b; Sibsagar Dist.,** Borpatra T. E. (Nr. Borhat), **183a,** Jorhat, **175; Sylhet Dist.,** Amo T. E., **187,** Begum Khan T. E., **187,** Nijpat Jaintiapur, **162a,** Teliapara T. E., **187.**

BENGAL.

Birbhum Dist., Bolpur, **191; Chittagong Dist.,** Pahartoli, **182a; Dacca Dist.,** Dacca, **MB. 152-35; Darjeeling Dist.,** Sukna, **165a; Jalpaiguri Dist.,** Birpara, **MB. 46-34,** Madarihat, **165a,** Meenglas, **165a,** Raja Bhat Khawa, **157b,** Sylee, **171.**

BIHAR.

Purnea Dist., Purnea, **155.**

BURMA LOWER.

Hanthawaddy Dist., Mingaladon, **166.**

BURMA UPPER.

North Hsenwi State (N. Shan States), Namtu, **157b.**

CHOTA NAGPUR.

Singhbhum Dist., Chiria, **157b,** Duia, **157b,** Dangoaposi, **MB. 186-33,** Unqua, **157b.**

HYDERABAD SOUTH.

Atraf-i-Balda Dist., Hyderabad, **149.**

KONKAN.

Goa, Old Goa, **MB. 37-34.**

ORISSA.

Kalahandi State, Sigor Kupa, **MB. 216-33.**

moghulensis.

BOMBAY DECCAN.

Belgaum Dist., Arag, **173,** Athni Road, **173; Kolhapur State,** Dhalgaon, **173,** Langerpeth, **173; Sholapur Dist.,** Chink Hill, **173,** Jath Road, **173,** Kalamb Road, **173,** Kuslamb, **173,** Padsali, **173,** Ramling, **173,** Yedsi, **173.**

HYDERABAD NORTH.

Osmanabad Dist., Hangul, **173,** Murud, **173,** Owasa Road, **173,** Thair, **173.**

KONKAN.

Thana Dist., Bhira (Andhra Valley), **MB. 79-33.**

MADRAS COAST NORTH.

Vizagapatam Dist., Chitikona, **MB. 31-34.**

NORTH-WEST FRONTIER PROVINCE.

Mohmands Territory, Galanai, **MB. 207-33.**

RAJPUTANA EAST.

Ajmer-Merwara Province, Ajmer, **MB. 19-34, 150.**

RAJPUTANA WEST.

Sirohi State, Delwara, **MB. 184-33,** Dundai, **MB. 184-33,** Hetamji, **MB. 184-33,** Jawai, **MB. 184-33,** Kumharwara, **MB. 184-33,** Mount Abu, **167,** Salgaon, **MB. 184-33.**

multicolor.

BALUCHISTAN.

Quetta-Pishin Dist., Quetta, **MB. 135-35.**

pallidus.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **MB. 182-33,** Mangaldai, **179a,** Tezpur, **179d; Goalpara Dist.,** Abhayapuri, **MB. 244-33,** Dhubri, **MB. 117-33; Lakhimpur Dist., 182b,** North Lakhimpur, **182a,** Pasighat, **179b; Nowgong Dist., 182b.**

BENGAL.

Birbhum Dist., Bolpur, **191; Calcutta,** Garden Reach, **159a; Chittagong Dist.,** Pahartoli, **182a; 24-Parganas Dist.,** Ukhila, **184.**

BOMBAY DECCAN.

Kolhapur State, Dhulgaon, **173; Sholapur Dist.,** Ashti, **173,** Babhulgaon, **173,** Bamani, **173,** Bohali, **173,** Pandharpur, **173,** Sangola, **173,** Wasud, **173.**

GUJRAT.

Kaira Dist., Bherai, **MB. 187-34,** Navagana, **MB. 179-34; Surat Dist.,** Bansda, **MB. 132-34,** Bulsar, **MB. 2-34,** Degom, **MB. 271-33,** Hond, **MB. 271-33,** Jalalpore, **MB. 275-33,** Kanbhai, **MB. 271-33,** Mahudi, **MB. 279-33,** Palan, **MB. 271-33.**

HYDERABAD NORTH.

Osmanabad Dist., Latur, **173.**

KONKAN.

N. Kanara Dist., Ambgaon, **MB. 64-34,** Bijankot, **MB. 49-34,** Chandguli, **MB. 49-34,** Hingaddi, **MB. 64-34,** Hunsemani, **MB. 49-34,** Kanadgal, **MB. 32-34,** Kimdargi, **MB. 49-34,** Kolikeri, **MB. 32-34,** Savagadde, **MB. 32-34.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Mercara, **169e*.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178c,** Naganhalli, **178a,** Nagoonhalli, **178f.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Patna State,** Villages along Kantabhanji-Sonepur projected railway line, **154b; Puri Dist.,** Khurda Road, **180.**

PUNJAB EAST AND NORTH.

Hissar Dist., Sirsa, **MB. 149-34; Jullundur Dist.,** Jullundur, **MB. 194-34; Rawalpindi Dist.,** Rawalpindi, **MB. 212-33.**

RAJPUTANA EAST.

Ajmer-Merwara Province, Ajmer, **150.**

RAJPUTANA WEST.

Sirohi State, Mount Abu, **MB. 184-33.**

UNITED PROVINCES WEST.

Meerut Dist., Meerut, **MB. 173-35; Moradabad Dist.,** Moradabad, **MB. 204-34.**

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* Doubtful record.

philippinensis.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Chardaur, **179c,** Lokra, **179c,** Mangaldai, **179a,** Tezpur, **182a; Goalpara Dist.,** Abhayapuri, **MB. 166-33,** Dhubri, **182a; Khasi and Jaintia Hills Dist.,** Nongpoh, **182a; Lakhimpur Dist.,** North Lakhimpur, **182a,** Pasighat, **179b; Nowgong Dist.,** Dimapur, **182a,** Nowgong, **182a; Sibsagar Dist.,** Borpatra T. E. (Nr. Borhat), **183a,** Jorhat, **175; Sylhet Dist.,** Begum Khan T. E., **187,** Nijpat Jaintiapur, **162a.**

BENGAL.

Birbhum Dist., Bolpur, **191; Chittagong Dist.,** Pahartoli, **182a,** Rangamatti, **165a; Darjeeling Dist.,** Sukna, **165a; Noakhali Dist.,** Rahamatpur, **181,** Sandwip (Harishpur), **181; 24-Parganas Dist.,** Sonarpur, **184,** Ukhila, **184.**

BOMBAY DECCAN.

Sholapur Dist., Mahisgaon, **173.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Puri Dist.,** Khurda Road, **180.**

pulcherrimus*.

BALUCHISTAN.

Loralai Dist., Loralai, **MB. 195-33.**

NORTH-WEST FRONTIER PROVINCE.

Peshawar Dist., Mardan, **MB. 102-35,** Nowshera, **MB. 152-33.**

PUNJAB EAST AND NORTH.

Ambala Dist., Ambala, **MB. 6-35; Gujranwala Dist.,** Chichoki Malian, **MB. 71-35; Patiala State,** Bhawanigarh, **159b,** Chuharpur Mirasian, **159b,** Patiala, **159b.**

RAJPUTANA EAST.

Ajmer-Merwara Province, Nasirabad, **MB. 174-35.**

RAJPUTANA WEST.

Bikaner State, Bijhey Bhawan, **174,** Gajner, **174,** Lallgarh, **174.**

SIND.

Karachi Dist., Belo, **160d,** Bhero Sumro, **160d,** Chuhar Jamali, **160d,** Daho, **160d,** Daro, **160d,** Geduro, **160d,** Habib Mullah, **160d,** Kandri, **160d,** Mirpur Bathor, **160d,** Mirzo Laghari, **160d,** Moghulbhin, **160d,** Sando Bandar, **160d,**

* Jafar (166) has recorded *pulcherrimus* from Mingaladon (Hanthawaddy Dist., Burma Lower) but the record appears to be very doubtful and needs confirmation.

Shahbandar, **160d,** Sujawal, **160d,** Pir Karim Shah, **160d,** Tar Khawaja, **160d; Khairpur State,** Kanasara, **160h,** Khairpur, **160h,** Lukman, **160h,** Tando Mastikhan, **160h; Larkana Dist.,** Berochandia, **193,** Bher, **193,** Dodai, **193,** Dokri, **193,** Ghari Khuda 'Baksh, **160g,** Masu Dero, **160g,** Miro Khan, **160g,** Nao Dero, **160g,** Nasirabad, **160g,** Naundero, **193,** Panjoo Dero, **160g,** Pir Jo Got, **160g,** Ratodero, **160g,** Tharo Wadho, **160g,** Warah, **160g; Upper Sind Frontier Dist.,** Chana, **160c,** Dari, **160c,** Gauspur, **160c,** Jacobabad, **160c,** Kandhkot, **160c,** Mirpur, **160c,** Ramzanpur, **160c,** Thul, **160c.**

ramsayi.

ASSAM.

Cachar Dist., Hailakandi, **182a; Darrang Dist.,** Mangaldai, **179a; Lakhimpur Dist., 182b,** North Lakhimpur, **179h; Nowgong Dist., 182b; Sibsagar Dist.,** Borpatra T. E. (Nr. Borhat), **183,** Jorhat, **176; Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

BENGAL.

Birbhum Dist., Bolpur, **191; Calcutta,** Garden Reach, **159a,** Salt Lakes, **165b; Noakhali Dist.,** Ijjatpur, **181,** Rahamatpur, **181; 24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BIHAR.

Purnea Dist., Purnea, **155.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Puri Dist.,** Khurda Road, **180.**

sergenti.

BALUCHISTAN.

Loralai Dist., Loralai, **MB. 69-35; Quetta-Pishin Dist.,** Quetta, **MB. 135-35.**

splendidus.

ASSAM.

Darrang Dist., Chardaur, **MB. 58-34; Goalpara Dist.,** Kachugaon, **163b, MB. 3-34; Kamrup Dist.,** Gauhati, **MB. 71-33.**

BENGAL.

Darjeeling Dist., Sindipung, **188,** Sukna, **165a.**

BOMBAY DECCAN.

Sholapur Dist., Kalamb Road, **173.**

GUJRAT.

Surat Dist., Bansda, **MB. 132-34.**

HYDERABAD NORTH.

Osmanabad Dist., Murud, **173.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Gonicoppal, **170a,** Kanur, **170e,** Nagarahole, **170d,** Ponampet, **170a,** Sampaje, **169c,** Siddapur, **170a,** Somwarpet, **169b,** Srimangala, **170a,** Suntikoppa, **169a.**

MYSORE.

Mysore Dist., Mysore, **178c,** Nagoonhalli, **178f.**

NORTH-WEST FRONTIER PROVINCE.

Peshawar Dist., Bargholi (Mardan), **MB. 63-35.**

ORISSA.

Puri Dist., Khurda Road, **180.**

PUNJAB EAST AND NORTH.

Karnal Dist., Kunjpura, **MB. 18-35.**

RAJPUTANA WEST.

Sirohi State, Mount Abu, **167.**

SIKKIM.

Monraing, **188.**

stephensi.

ASSAM.

Darrang Dist., Chardaur, **MB. 58-34,** Lokra, **179c; Lakhimpur Dist.,** Namsang, **182a.**

BALUCHISTAN.

Zhob Dist., Gulkach, **MB. 69-34,** Hindubagh, **MB. 136-35.**

BENGAL.

Calcutta, Garden Reach, **159a; Jalpaiguri Dist.,** Dundina (Birpara), **MB. 294-33.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173,** Athni Road, **173; Khandesh East,** Bhusawal, **MB. 51-34; Kolhapur State,** Bolwad, **173,** Dhalgaon, **173,** Dhulgaon, **173,** Gulvanchi, **173,** Kavathe Mahankal, **173,** Langerpeth, **173,** Miraj, **173,** Sulgare, **173; Poona Dist.,** Dhairi, **MB. 126-33,** Dhankodi, **MB. 126-33,** Khadakwasla,

MB. 126-33, Nanded, **MB. 126-33,** Parvati, **MB. 126-33; Sholapur Dist.,** Ashti, **173,** Bamani, **173,** Barsi Town, **173,** Babhulgaon, **173,** Bohali, **173,** Chink Hill, **173,** Jath Road, **173,** Javla, **173,** Kalamb Road, **173,** Kuslamb, **173,** Laul, **173,** Mahisgaon, **173,** Modlimb, **173,** Padsali, **173,** Pandharpur, **173,** Pangri, **173,** Ramling, **173,** Sangola, **173,** Shendri, **173,** Uplai, **173,** Wasud, **173,** Yedsi, **173.**

BURMA UPPER.

North Hsenwi State (N. Shan States), Namtu, **MB. 54-34.**

CHOTA NAGPUR.

Palamau Dist., Barwadih, **MB. 218-34.**

HYDERABAD NORTH.

Osmanabad Dist., Dhoki, **173,** Hangul, **173,** Latur, **173,** Murud, **173,** Neoli, **173,** Owasa Road, **173,** Palsap, **173,** Thair, **173.**

KONKAN.

North Kanara Dist., Anagod, **MB. 25-36.**

MALABAR.

Coorg Province, Virajpet, **169a.**

MYSORE STATE.

Kadur Dist., Muthigepura **178b; Mysore Dist.,** Hulikere Tunnel Works, **190,** Mysore, **178c,** Nagoonhalli, **178f.**

NORTH-WEST FRONTIER PROVINCE.

Mohmands Territory, Galanai, **MB. 207-33; Peshawar Dist.,** Bargholi (Mardan), **MB. 63-35.**

PUNJAB EAST AND NORTH.

Gujranwala Dist., Chichoki Malian, **MB. 71-35; Hissar Dist.,** Sirsa, **MB. 134-34; Patiala State,** Badshahpur, **159c,** Mohindergarh, **159c.**

RAJPUTANA WEST.

Bikaner State, Bikaner, **174,** Bijhey Bhawan, **174,** Gajner, **174,** Lallgarh, **174; Sirohi State,** Moch, **MB. 184-33.**

SIND.

Karachi Dist., Karachi, **MB. 74-35; Khairpur State,** Baharo Khan Lashari, **160h,** Burdi, **160h,** Fatehpur, **160h,** Gambat, **160h,** Khairpur, **160h,** Khanpur, **160h,** Kohora, **160h,** Lukman, **160h,** Paneroo, **160h,** Ramzan Phul Poto, **160h,** Sohoo, **160h,** Tando Mastikhan, **160h,** Umaid Ali Lashri, **160h; Larkana Dist.,** Kambar, **160g,** Miro Khan, **160g,** Tharo Wadho, **160g; Sukkur Dist.,** Pano Akil, **160e; Thar and Parkar Dist.,** Chellar, **160b; Upper Sind Frontier Dist.,** Kandhkot, **160c.**

UNITED PROVINCES WEST.

Jhansi Dist., Jhansi, **MB. 111-35.**

WAZIRISTAN.

Bannu Area, Mir Ali, **MB. 89-33; Derajat Area,** Wana, **MB. 205-34.**

subpictus.

ASSAM.

Darrang Dist., Chardaur, **MB. 107-33,** Lokra, **179c,** Mangaldai, **182a; Garo Hills Dist.,** Tura, **179g; Goalpara Dist.,** Abhayapuri, **MB. 115-33,** Dhubri, **182a; Lakhimpur Dist.,** Bordubi, **182a,** North Lakhimpur, **182a,** Pasighat, **179b; Nowgong Dist.,** Dimapur, **182a.**

BALUCHISTAN.

Zhob Dist., Gulkach, **MB. 69-34.**

BENGAL.

Birbhum Dist., Bolpur, **191; Calcutta,** Garden Reach, **159a,** Salt Lakes, **165; Chittagong Dist.,** Pahartoli, **182a; Darjeeling Dist.,** Dungra, **188,** Kalimpong, **188,** Melli, **188,** Sindipung, **188,** Tista Bazar, **188; Howrah Dist.,** Lillooah, **MB. 170-33; Noakhali Dist.,** Nalchira, **181; 24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173,** Athni Road, **173; Kolhapur State,** Bolwad, **173,** Dhalgaon, **173,** Dhulgaon, **173,** Gulvanchi, **173,** Kavathe Mahankal, **173,** Langerpeth, **173,** Miraj, **173,** Sulgare, **173; Poona Dist.,** Dhairi, **MB. 236-33,** Hingne, **MB. 126-33,** Kothrud, **MB. 126-33,** Parvati, **MB. 126-33,** Vadgaon, **MB. 126-33,** Vithalwadi, **MB. 126-33,** Warji, **MB. 126-33,** Yerandavne, **MB. 126-33; Sholapur Dist.,** Ashti, **173,** Babhulgaon, **173,** Bamani, **173,** Barsi Town, **173,** Bohali, **173,** Chink Hill, **173,** Jath Road, **173,** Javla, **173,** Kalamb Road, **173,** Kuslamb, **173,** Laul, **173,** Mahisgaon, **173,** Modlimb, **173,** Padsali, **173,** Pangri, **173,** Ramling, **173,** Sangola, **173,** Shendri, **173,** Uplai, **173,** Wasud, **173,** Yedsi, **173.**

BURMA LOWER.

Hanthawaddy Dist., Mingaladon, **166.**

BURMA UPPER.

Magwe Dist., Taungkanyo, **MB. 218-33,** Theingone, **MB. 218-33.**

CENTRAL INDIA WEST.

Bhopal State, Bhopal, **MB. 193-34.**

GUJRAT.

Kaira Dist., Bherai, **MB. 187-34,** Chalindra, **MB. 188-34,** Navagana, **MB. 179-34,** Nayaka, **MB. 179-34; Surat Dist.,** Agashi, **MB. 271-33,** Atgam,

MB. 271-33, Bansda, **MB. 56-34,** Bulsar, **MB. 292-33,** Hond, **MB. 271-33,** Jalalpur, **MB. 275-33,** Kaliari, **MB. 271-33,** Khudwal, **MB. 271-33,** Mandvi, **MB. 274-33,** Pardi, **MB. 279-33,** Pievi, **MB. 279-33,** Satan, **MB. 279-33,** Sarpore, **MB. 279-33.**

HYDERABAD NORTH.

Osmanabad Dist., Dhoki, **173,** Hangul, **173,** Latur, **173,** Murud, **173,** Neoli, **173,** Owasa Road, **173,** Palsap, **173,** Thair, **173.**

KONKAN.

N. Kanara Dist., Balkhand, **MB. 25-34,** Barhalli, **MB. 25-34,** Bharni, **MB. 49-34,** Bhomnalli, **MB. 49-34,** Buichgod, **MB. 49-34,** Hiresar, **MB. 49-34,** Kaninalli, **MB. 64-34,** Kotmani, **MB. 64-34,** Nagarkan, **MB. 32-34,** Sabassalli, **MB. 64-34; Thana Dist.,** Thana, **MB. 272-33.**

MADRAS COAST NORTH.

Kistna Dist., Chitlopudi, **MB. 94-35.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Fraserpet, **169a,** Gonicoppal, **170a,** Kanur, **170e,** Nagarahole, **170d,** Ponampet, **170a,** Sampaje, **169c,** Siddapur, **170a,** Srimangala, **170a,** Suntikoppa, **169a,** Tittimatti, **170f,** Virajpet, **169b.**

MYSORE STATE.

Kadur Dist., Mudigere, **178a; Kolar Dist.,** Kamadanahalli, **190; Mysore Dist.,** Hulikere Tunnel Works, **190,** Mysore, **178c,** Nagoonhalli, **178f.**

NORTH-WEST FRONTIER PROVINCE.

Mohmands Territory, Galanai, **MB. 207-33.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Patna State,** Villages along Kantabhanji-Sonepur projected railway line, **154b; Puri Dist.,** Khurda Road, **180.**

PUNJAB EAST AND NORTH.

Gujranwala Dist., Chichoki Malian, **MB. 71-35; Gurdaspur Dist.,** Bakloh, **164; Hissar Dist.,** Sirsa, **MB. 126-34; Patiala State,** Bhatinda, **159b,** Chuharpur Mirasian, **159b,** Dadhera, **159b,** Kalyan, **159b,** Madok, **159b,** Patiala, **159b.**

RAJPUTANA WEST.

Bikaner State, Bikaner, **174; Sirohi State,** Delwara, **MB. 184-33,** Gora Chhapra, **MB. 184-33,** Kala Chhapra, **MB. 184-33,** Kumharwara, **MB. 184-33,** Oria, **MB. 184-33.**

SIND.

Karachi Dist., Bano, **160d,** Belo, **160d,** Bhero Sumro, **160d,** Chang, **160d,** Chuhar Jamali, **160d,** Dari, **160d,** Daro, **160d,** Habib Mullah, **160d,** Haider Ali Shah, **160d,** Joakh, **160h,** Kandri, **160d,** Kehran, **160d,** Khairo Jat, **160d,** Ladiun, **160d,** Laikpur, **160d,** Machi, **160d,** Mirpur Bathoro, **160d,** Mirzo Laghari, **160d,** Mughulbhin, **160d,** Mullah, **160d,** Pir Karim Shah, **160d,** Sando Bandar, **160d,** Shahbandar, **160d,** Sidik Shora, **160d,** Sujawal, **160d,** Tal, **160d,** Tar Khawaja, **160d; Khairpur State,** Baharo Khan Lashari, **160h,** Burdi, **160h,** Kanasara, **160h,** Khairpur, **160h,** Kohora, **160h,** Ramzan Phul Poto, **160h,** Tando Masti Khan, **160h; Larkana Dist.,** Bher, **193,** Bherochandia, **193,** Dodai, **193,** Dokri, **193,** Ghari Khuda Buksh, **160g,** Masu Dero, **160g,** Miro Khan, **160g,** Nao Dero, **160g,** Nasirabad, **160g,** Naundero, **193,** Panjoo Dero, **160g,** Pir Jo Got, **160g,** Ratodero, **160g,** Tharo Wado, **160g,** Warah, **160g; Nawabshah Dist.,** Bhiria, **160a,** Kazi Ahmed, **160a,** Mari, **160a,** Nawabshah, **160a; Upper Sind Frontier Dist.,** Bhalaindina Abad, **160c,** Chana, **160c,** Dakhan, **160c,** Dari, **160c,** Dil Murad Koso, **160c,** Hayabat, **160c,** Gauspur, **160c,** Kandhkot, **160c,** Kashmor, **160c,** Mirpur, **160c,** Maulabad, **160c,** Ramzanpur, **160c,** Shahdadkot, **160c,** Thul, **160c.**

WAZIRISTAN.

Derajat Area, Jandola, **MB. 172-35.**

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BENGAL.

Calcutta, Brace Bridge, **159a,** Garden Reach, **159a,** Kristopur, **159a,** Majerhat, **159a,** Sealdah, **159a,** Shambazar, **159a; Dacca Dist.,** Hasanabad, **159a,** Taki, **159a; Howrah Dist.,** Changail, **159a,** Howrah, **159a,** Ulubaria, **159a; 24-Parganas Dist.,** Bansra, **159a,** Falta, **159a,** Manshapukar, **159a,** Piali, **159a.**

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BALUCHISTAN.

Loralai Dist., Loralai, **MB. 91-34; Zhob Dist.,** Gulkach, **MB. 69-34,** Hindubagh, **MB. 118-35.**

NORTH-WEST FRONTIER PROVINCE.

Chitral State, Chitral, **MB. 174-34; Mohmands Territory,** Galanai, **MB. 207-33.**

WAZIRISTAN.

Derajat Area, Jandola, **MB. 172-35.**

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ASSAM.

Darrang Dist., Mangaldai, **179a; Goalpara Dist.,** Abhayapuri, **MB. 210-33; Kamrup Dist.,** Gauhati, **179e; Lakhimpur Dist.,** North Lakhimpur, **179h; Sibsagar Dist.,** Jorhat, **175; Sylhet Dist.,** Nijpat Jaintiapur, **162a,** Sylhet, **MB. 17-34.**

BENGAL.

Birbhum Dist., Bolpur, **191; Calcutta,** Garden Reach, **159a; Nadia Dist.,** Birnagar, **153,** Krishnagar, **189; 24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BOMBAY DECCAN.

Ahmednagar Dist., Ahmednagar, **MB. 174-33; Poona Dist.,** Kothrud, **MB. 200-33,** Poona, **MB. 112-34; Sholapur Dist.,** Bohali, **173,** Kurduvadi, **MB. 175-33,** Pandharpur, **173.**

BURMA LOWER.

Rangoon Dist., Rangoon, **168.**

KONKAN.

North Kanara Dist., Targar, **MB. 293-33.**

MADRAS COAST NORTH.

Ganjam Dist., Chatrapur, **MB. 271-31; Vizagapatam Dist.,** Muniguda, **MB. 216-33.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **MB. 61-34, 177.**

MALABAR.

Coorg Province, Hallery, **192,** Sampaje, **169c,** Virajpet, **169b.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178c.**

ORISSA.

Puri Dist., Khurda Road, **180.**

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ASSAM.

Garo Hills Dist., Tura, **179g; Khasi and Jaintia Hills, 182b.**

BENGAL.

Birbhum Dist., Bolpur, **191.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173; Kolhapur State,** Bolwad, **173,** Dhalgaon, **173,** Dhulgaon, **173,** Gulvanchi, **173,** Kavathe Mahankal, **173,** Langerpeth, **173,** Miraj, **173; Poona Dist.,** Dhairi, **MB. 236-33; Sholapur Dist.,** Ashti, **173,** Babhulgaon, **173,** Bamani, **173,** Barsi Town, **173,** Chink Hill, **173,** Jath Road, **173,** Kalamb Road, **173,** Kurduvadi, **173,** Kuslamb, **173,** Laul, **173,** Mahisgaon, **173,** Modlimb, **173,** Padsali, **173,** Pangri, **173,** Ramling, **173,** Shendri, **173,** Uplai, **173,** Yedsi, **173.**

CHOTA NAGPUR.

Palamau Dist., Barwadih, **MB. 218-34; Ranchi Dist.,** Kamdera, **MB. 259-32; Singhbhum Dist.,** Noamundi, **186.**

GUJRAT.

Panch Mahals Dist., Freeland Gunj, **MB. 229-33.**

HYDERABAD NORTH.

Osmanabad Dist., Dhoki, **173,** Hangul, **173,** Latur, **173,** Murud, **173,** Neoli, **173,** Owasa Road, **173,** Palsap, **173,** Thair, **173.**

KONKAN.

Thana Dist., Andhra Valley (Bhira), **MB. 79-33.**

ORISSA.

Patna State, Villages along Kantabhanji-Sonepur projected railway line, **154b.**

RAJPUTANA EAST.

Ajmer-Merwara Province, Ajmer, **150, MB. 254-33.**

RAJPUTANA WEST.

Sirohi State, Delwara, **MB. 184-33,** Oria, **MB. 184-33,** Torna, **MB. 184-33.**

turkhudi.

BALUCHISTAN.

Loralai Dist., Loralai, **MB. 195-33.**

BOMBAY DECCAN.

Belgaum Dist., Arag, **173,** Athni Road, **173, Kolhapur State,** Dhalgaon, **173,** Dhulgaon, **173,** Gulvanchi, **173,** Kavathe Mahankal, **173,** Langerpeth, **173,** Sulgare, **173; Poona Dist.,** Kothrud, **MB. 126-33,** Nanded, **MB. 126-33; Sholapur Dist.,** Bamani, **173,** Bohali, **173,** Jath Road, **173,** Javla, **173,** Mahisgaon, **173,** Pandharpur, **173,** Pangri, **173,** Ramling, **173,** Sangola, **173,** Uplai, **173,** Wasud, **173,** Yedsi, **173.**

HYDERABAD NORTH.

Osmanabad Dist., Dhoki, **173,** Latur, **173,** Neoli, **173,** Owasa Road, **173,** Palsap, **173,** Thair, **173.**

NORTH-WEST FRONTIER PROVINCE.

Mohmands Territory, Galanai, **MB. 207-33.**

RAJPUTANA EAST.

Ajmer-Merwara Province, Ajmer, **MB. 31-35.**

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ASSAM.

Cachar Dist., **182b;** **Darrang Dist.,** Mangaldai, **179a;** **Lakhimpur Dist.,** Bordubi, **182a;** **Sibsagar Dist.,** Jorhat, **176;** **Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

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ASSAM.

Cachar Dist., Haflong, **183b;** **Darrang Dist.,** Chardaur, **179c,** Lokra, **179c,** Mangaldai, **179a,** Tezpur, **179d;** **Garo Hills Dist.,** Tura, **179g;** **Goalpara Dist.,** Abhayapuri, **MB. 115-33,** Dhubri, **182a;** **Khasi and Jaintia Hills Dist.,** Nongpoh, **182a,** Umran, **182a;** **Lakhimpur Dist.,** Bordubi, **182a,** Digboi, **MB. 161-33,** North Lakhimpur, **179h;** Pasighat, **179b;** **Manipur Dist.,** Imphal, **182a;** **Nowgong Dist.,** Dimapur, **182a;** Nowgong, **182a;** **Sibsagar Dist.,** Borpatra T. E. (Nr. Borhat), **183a,** Jorhat, **175;** **Sylhet Dist.,** Nijpat Jaintiapur, **162a.**

BENGAL.

Calcutta, Garden Reach, **159a,** Salt Lakes, **165b;** **Chittagong Dist.,** Pahartoli, **182a;** **Darjeeling Dist.,** Chibe, **188,** Dungra, **188,** Giellekhella, **188,** Kalimpong, **188,** Melli, **188,** Riyang, **188,** Sindipung, **188,** Tista Bazar, **188;** **Howrah Dist.,** Lillooah, **MB. 170-33;** **Jalpaiguri Dist.,** Madarihat, **165a;** **Noakhali Dist.,** Char Bata, **181,** Char Iswar Ray, **181,** Chhagatnaia, **181,** Chitra Khali, **181,** Matua, **181,** Nalchira, **181,** Rahamatpur, **181,** Sandwip Town (Harishpur), **181;** **24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BIHAR.

Purnea Dist., Purnea, **155.**

BOMBAY DECCAN.

Poona Dist., Dhairi, **MB. 236-33,** Vadgaon, **MB. 200-33;** **Sholapur Dist.,** Kurduvadi, **MB. 175-33.**

BURMA UPPER.

Magwe Dist., Taungkanyo, **MB. 218-33,** Theingone, **MB. 218-33;** **Minbu Dist.,** Mezali, **161b.**

CHOTA NAGPUR.

Singhbhum Dist., Noamundi, **186.**

GUJRAT.

Surat Dist., Bansda, **MB. 87-34.**

HYDERABAD SOUTH.

Atraf-i-Balda Dist., Hyderabad, **149.**

KONKAN.

North Kanara Dist., Belambi, **MB. 64-34,** Hiriyal, **MB. 49-34,** Yellapur, **MB. 293-33.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177.**

MALABAR.

Coorg Province, Gonicoppal, **170a,** Mercara, **192, 169a,** Ponampet, **170a,** Siddapur, **170a,** Somwarpet, **192,** Suntikoppa, **169a.**

MYSORE STATE.

Kadur Dist., Muthigepura, **178b; Mysore Dist.,** Mysore, **178c,** Nagoonhalli, **178f.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Patna State,** Villages along Kantabhanji-Sonepur projected railway line, **154b; Puri Dist.,** Khurda Road, **180.**

SIKKIM.

Duga, **188,** Majhitar, **188,** Rungo, **188,** Sankakhola, **188,** Sichygong, **188,** Sington, **188,** Tadong, **188.**

varuna.

ASSAM.

Darrang Dist., Chardaur, **179c,** Lokra, **179c,** Mangaldai, **MB. 161-33; Garo Hills Dist.,** Tura, **179g; Goalpara Dist.,** Abhayapuri, **MB. 11-34,** Gauripur, **MB. 25-35; Khasi and Jaintia Hills Dist.,** Shillong, **MB. 8-34; Lakhimpur Dist.,** Pasighat, **179b; Sibsagar Dist.,** Cinnamara, **MB. 198-34; Sylhet Dist.,** Sylhet, **162b.**

BENGAL.

Calcutta, Garden Reach, **159a,** Salt Lakes, **165b; Nadia Dist.,** Krishnagar, **189; Noakhali Dist.,** Chitrakhali, **181; 24-Parganas Dist.,** Sitola, **184,** Ukhila, **184.**

BOMBAY DECCAN.

Dharwar Dist., Hubli, **157b; Sholapur Dist.,** Bohali, **173,** Pandharpur, **173.**

CHOTA NAGPUR.

Singhbhum Dist., Duia, **157b,** Unqua, **157b.**

GUJRAT.

Baroda State, Baroda, **157b.**

KONKAN.

Goa, Satary, **MB. 37-34; North Kanara Dist.,** Yellapur, **157b.**

MADRAS SOUTH-EAST.

Coimbatore Dist., Valparai, **177, MB. 61-34.**

MALABAR.

Coorg Province, Mercara, **157b; Travancore State,** Kulesekharam, **165c.**

MYSORE STATE.

Bangalore Dist., Bangalore, **157b; Chitaldrug Dist.,** Hiriyur, **178d; Kadur Dist.,** Muthigepura, **178b.**

ORISSA.

Balasore Dist., Bhadrak, **154a; Cuttack Dist.,** Cuttack, **157b; Kalahandi State,** Sigor Kupa, **MB. 216-33; Puri Dist.,** Khurda Road, **180.**

UNITED PROVINCES EAST.

Gorakhpur Dist., Gorakhpur, **MB. 221-34.**

UNITED PROVINCES WEST.

Pilibhit Dist., Banbasa, **158.**

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A DISCUSSION ON THE INFECTIVITY SURVEYS AND FEEDING HABITS OF ANOPHELINE MOSQUITOES IN THE ORIENTAL REGION, WITH SPECIAL REFERENCE TO ASSAM AND NORTHERN BENGAL.

BY

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AN investigation was carried out during 1933 and 1934 to determine the feeding habits of anopheline mosquitoes in Assam and Northern Bengal. The results of this work have recently been published (Ramsay, Chandra and Lamprell, 1936).

In comparing the results obtained with those of other investigators, the author has been impressed by the very divergent findings recorded in relation to the feeding habits of the same species of *Anopheles* in different areas. Similar differences are also reported in regard to the malaria infection rate of the same species under both natural and experimental conditions. We are, therefore, confronted with the problem whether these recorded variations may be attributable to fundamental differences in the biological and physiological characters of single species that are believed to be entomological entities, or whether they are the result of varied environmental conditions.

With regard to infectivity indices, many writers have suggested variations in zoophilism as an explanation. Nevertheless, considerable doubt still exists as to why a species of *Anopheles*, which is recognised as an important malaria vector in one locality, is, on the evidence of a few hundred, or possibly a few thousand, dissections, stated to be of no importance as a carrier of the disease in a neighbouring locality. The present investigation was undertaken in an attempt to throw further light on this problem.

The work on the feeding habits of anophelines, reported by Ramsay *et al.* (1936), was carried out in Assam and Northern Bengal in localities where the population lived in close association with cattle, the ruminant animals being almost as numerous as the human beings. These workers determined the sources

of the blood meals found in 19 species of anophelines caught in nature under the conditions mentioned. In those species in which only a few specimens were examined, the data were insufficient to base any reliable conclusion on them. The androphilic indices were calculated, therefore, only in those species in which over 100 specimens were examined. The results are recorded in Table I.

The feeding habits of the species of *Anopheles* found in Assam and Northern Bengal have been investigated in other parts of the Oriental region by several workers, the reports of two of whom may be especially mentioned.

Laurel (1934), working in the Philippines in 1932, collected adults outside houses at night, mainly by means of traps baited with human beings. He also collected, during the day, mosquitoes resting on vegetation and in cracks in masonry, etc., along the edges of breeding places, and he recorded the results of the examination of specimens from the two sources separately. He studied altogether 15 species, 11 of which have been found in Assam and investigated by workers of the Ross Institute. Where sufficiently large numbers have been examined for accurate percentages to be calculated, the proportion of those found to have taken a human blood meal, and caught at night near houses, is not dissimilar from the Ross Institute findings. In the case of *A. minimus*, caught at night near houses, Laurel (1934) found that 96 were positive against either human, cow or caribou serum, and of these, 64 reacted for human serum (67 per cent); but of those caught in the day-time, in outdoor resting places near breeding places, only 94 out of 1,014 found positive (9 per cent) reacted for human serum.

The work of Walch (1932) in Dutch East Indies is also of particular interest. This worker examined blood meals from mosquitoes caught in two areas, (*a*) where cattle were unusually scarce, and (*b*) where cattle were numerous. Eight of the 11 species studied by Walch have also been investigated by the Ross Institute workers in Assam and Northern Bengal.

The figures given by Walch (1932) are as follows :—

Name of species.	CATTLE SCARCE.		CATTLE IN NORMAL NUMBERS.	
	Number tested.	Per cent with human blood.	Number tested.	Per cent with human blood.
A. vagus	..	..	256	1
A. aconitus	137	61	229	12
A. maculatus	38	97	45	11
A. kochi	6	17	48	4
A. tessellatus	19	47	23	..
A. annularis (*A. fuliginosus*) ..	2	50	50	10
A. leucosphyrus	102	99	..	..
A. barbirostris	13	31	46	9

It is rather striking that, in the two sets of figures given by Laurel (1934) from the Philippines, in the two sets recorded by Walch (1932) in the Dutch East Indies, and in those from Assam, the relative degrees of zoophilism in the different species are similar. For instance, *A. leucosphyrus* is markedly androphilic in Assam and in the Dutch East Indies; *A. minimus* is markedly

androphilic in Assam and in the Philippines, and in all three countries *A. maculatus* occupies an intermediate portion, while *A. vagus* is markedly zoophilic.

For some years the apparent discrepancy between the recorded distribution of *A. maculipennis* and of malaria in Europe, puzzled workers. They postulated that it existed in sub-species with distinct biological characteristics before any anatomical differences could be found to justify such a division. Now *A. maculipennis*, according to Hackett (1934), can be divided on constant morphological differences into six distinct varieties, which can be identified on egg types. These sub-species differ in biological characters, such as choice of breeding sites, domesticity, feeding preferences, etc., but each is 'broadly homogeneous throughout its range in spite of adaptation to local conditions' and it appears that hybridisation cannot occur in nature. Are there such marked physiological and biological differences between *A. culicifacies*, *A. umbrosus* and *A. maculatus* in different localities as to lead one to expect that a more careful investigation would show that they can be divided into entomological sub-species on morphological differences? In the species under review, it would appear from the available data that probably the tendency to androphilism or zoophilism is constant for each species, the exact ratio depending only on the relative availability of human and animal blood in the locality. In other words, if precisely equal opportunity of feeding on cattle or human beings were given to a certain number of individuals of one species, a definite proportion would choose each, and it seems likely that that proportion would remain constant for the species wherever investigated. In the matter of selection of breeding sites, there is a similar constancy in each species in whatever locality it is found. *A. minimus*, for instance, although it may be found in stagnant water, or occasionally in silty water, shows everywhere a marked preference for clear running water with a grassy edge.

On reviewing the divergent results of experimental infection in the light of recent work, it does not seem surprising that there should be an apparent discrepancy in observations recorded in different localities. It has been demonstrated very clearly that the suitability of a malaria case for infecting mosquitoes depends not only on the number of gametocytes but also on the 'quality' of the gametocytes. Green (1929), in the Institute for Medical Research, Kuala Lumpur in Malaya, showed that in one batch of *A. maculatus* fed on a case of malignant tertian malaria with one gametocyte to 200 leucocytes, some members of the batch became infected, whilst in another batch fed on a case with as many as 60 gametocytes to 100 leucocytes, none became infected. Yorke and Macfie (1924) attributed such differences to the state of the patient's blood. James (1931) considered the differences may be accounted for by the 'quality' of the gametocytes, and estimates the infectivity of a case on the number of 'exflagellating male forms' found in a moist chamber preparation in a given time. It has also been shown by various workers that some individual mosquitoes in a batch are more refractory to infection than others. James (1931) has suggested that the lining membrane in the stomach wall of some individuals is less permeable to vermicules than that of others. Although there is this variation in individuals of the same species, it would seem justifiable to assume, unless there is definite evidence to the contrary, that the degree of variation is constant in that species wherever found; by this is meant, if a certain number of individuals of a species ingested an equal number of

gametocytes from malaria cases, although a proportion will remain uninfected and a proportion will be heavily infected, those proportions will remain constant for that species in every area.

However, other factors which may on further work be found to have some influence, are (*a*) variations in the potency of different strains of species of *Plasmodium* to infect mosquitoes, and (*b*) differences of environment in localities affecting the average length of life of the individuals of a species, or the average number of blood meals ingested during its life. In Europe strains of varying potency have been discovered, causing different clinical manifestations, and it appears possible that the strains may vary in potency to the mosquitoes. In Assam, for many years, there has been immigration on a very large scale from practically every province in India; every year thousands of coolies are imported from other provinces to work on tea estates. If there are plasmodial strains with differing potencies in India, one would expect many of them to have been introduced into Assam and the most potent strain would be the predominant one. Similarly, in Malaya there has been immigration on a large scale over a long period of years from India and from China. It is conceivable that the prevailing strains of *P. falciparum* in Assam, Malaya and the Dutch East Indies may be different in their selective action on anopheles. With regard to the other factor, it may be that climatic conditions in one locality, although conducive to prolific breeding of a species, may not be favourable to a long life, *i.e.*, the average length of life of the insects in one district being only a few days in natural conditions—insufficient for the development of sporozoites, and thus accounting for gut infections only being found in some cases.

Dr. Ramsay has very kindly placed at the writer's disposal the results of over 100,000 dissections, representing the work done on anopheline infectivity up to the end of 1934 by himself and by his collaborators. Many of the observations contributing to this total, have been published at various times but some have so far not been recorded. In addition to the dissections done by the Ross Institute observers in Assam, there has been a certain amount of work done by the Assam Medical Research Society. The former body has directed its attention mainly to the tea industry, and all the mosquitoes dissected by its workers have been caught on tea estates. The latter body has directed its attention mainly to Government land, and the mosquitoes dissected by its workers have, according to a private communication from Dr. Savage, formerly Malaria Research Officer of the Assam Medical Research Society, been caught mainly under urban conditions. A comparison of the results, in the light of the findings of the investigation into feeding habits, is most interesting. Generally speaking, the relationship of ruminant animals and man in urban populations is much less intimate than it is on tea estates. Under urban conditions one would expect, therefore, to find that more mosquitoes with zoophilic tendencies are forced to resort to human blood than would be the case on tea estates. The more closely men and cattle are intermingled the greater will be the proportion that succeeds in choosing blood for which a preference is shown. The main differences in the findings of these two organisations are that the records published by Savage (1933) show a higher proportion of infected *A. maculatus*, and he also found *A. philippinensis* to be infected. Amongst the tea estate populations only 5 4 per cent and 6·4 per cent of *A. maculatus* and *A. philippinensis* respectively, fed on human blood in any one meal. To what extent

the species feed on man in urban populations in Assam is not recorded, but one would expect that a greater percentage would feed on human blood, and this factor may account for the difference in the infectivity rates.

In attempting to compare the Assam dissections with those of the same species in other parts of the world where they had been investigated, a good deal of difficulty has been encountered. A number of observers have recorded only 'total infected' or 'percentage infected' in a series examined. In some cases where the number of 'positive guts' or 'positive glands' is given, it is not clear if the observer has dissected both guts and glands in the series.

The first question that arose was with regard to the best basis for the comparison. Should the details of gut and gland infection be ignored, and the 'total infection' only be made the basis, or should the series in which 'total infection' only has been noted be omitted? The problem under consideration is the importance of different species as vectors of malaria in Assam and in other localities in the Oriental region. On precisely what factors does the importance of a species of anopheline as a vector of malaria in any community depend? These may be expressed as follows:—

1. The average gametocyte rate of the community under consideration.
2. The density of the carrier species that may be found amongst that community.
3. The proportion of each of these species that will bite man at any blood feed and so be liable to ingest gametocytes, or inject sporozoites.
4. The proportion in each species of those that bite man in which ingested gametocytes will develop into sporozoites.
5. The proportion of those in which sporozoites have developed that will once more feed on man whilst the salivary gland is infected.

For the practical malariologist *the* factor of ultimate importance is the actual numerical prevalence of mosquitoes with salivary gland infection that at any period are feeding on the blood of the community in which he is trying to apply anti-mosquito methods to control malaria.

It may be that, although in one locality species which are known to be readily susceptible to infection are to be found in large numbers, they will feed almost entirely on cattle and so are of no practical importance as vectors. Again, it may be that, although a definite proportion of a species can be found with infected mid-guts, the species is, nevertheless, of little importance because, for some reason, a negligible number of individuals of that species with salivary-gland infection may return to that community. With regard to the importance of mid-gut infection, Swellengrebel and de Buck (1931), working with *A. maculipennis,* came to the conclusion that the mid-gut infectivity ratio was practically identical with the salivary-gland infectivity ratio, and that their results 'should remove all doubt as to the accuracy of the oöcyst rate as a measure to test the suitability of *A. maculipennis* to transmit malaria'. They conclude that this probably applies to other species as well. This view, however, is not confirmed by the work of James (1931) on *A. maculipennis* fed on quartan carriers; nor is it confirmed by the dissections of anopheles found infected in nature. It will be seen from Table III that, in over 6,000 dissections of *A. kochi,* four gut infections have been recorded and no gland ones; in over 15,000 dissections of *A. philippinensis* in Assam, four guts have been found

infected and no glands; and in over 6,000 dissections of *A. aconitus** eight guts and, again, no glands have been found infected. In the case of *A. culicifacies* and *A. maculatus*, considering the totals for all localities, the oöcyst rate was found to be much higher than the sporozoite rate.

For these reasons, in attempting to select a basis for comparison of dissection results for the whole Oriental region, it was decided to exclude all figures of series in which 'total infection' only is recorded. The figures for each locality shown in Table III have been computed in the following manner: With certain omissions, which will be subsequently mentioned, all the series by different observers for each locality recorded in the two papers of Covell (1927, 1931) have been added together. An exhaustive search of the most recent reports of dissections has not been made as in many cases totals are sufficiently large for comparison. The results of the recent work of Toumanoff (1933) in Tonkin have, however, been added and also the figures of dissection of *A. maculatus* by Gater (1933) from Malaya. There are also included a series of 19 dissections by Watson (1921) and the figures of dissections of *A. jeyporiensis*, *A. varuna* and *A. fluviatilis* in Travancore by Iyengar (1934). The Ross Institute figures included are those in Table II of this paper, and the Assam Medical Research Society figures are the results of three years' dissections (*vide* Savage, 1933). In compiling the table, every series of natural infections from the papers by Covell (1927, 1931) have been included, with the following exceptions :—All series have been omitted in which a figure is given for 'total infected' or 'percentage infected', but in which neither the gut nor the gland positives are given. The 15,000 dissections made by Sweet (1929-30), in Mysore, in which he found not a single infected specimen have also been omitted, nor does the table include dissections of series, the exact species of which is uncertain, such as those recorded as 'Fuliginosus group', 'Rossi', 'Sinensis' and 'Hyrcanus'. In some instances a difficulty has arisen owing to observers having recorded a slight difference in the number of guts and glands actually examined in one series; for example, in a series of *A. culicifacies* by Covell and Baily (1930), it is recorded that 785 guts and 776 glands were examined; in this case, and in three or four similar instances, the larger figures have been taken.

It will be seen from Table III that, where sufficient numbers have been dissected to allow only small probable errors, *A. culicifacies*, *A. maculatus*, *A. minimus*, *A. philippinensis*, *A. stephensi* and *A. umbrosus* have been found infected throughout the Oriental region. Work on *A. fluviatilis* is still limited, but Measham and Chowdhury (1934) have recently shown it to be an important vector in South India. *A. annularis*, *A. jeyporiensis* and *A. ramsayi* have been found infected to lesser degrees, but might prove to be important carriers in some communities. *A. aconitus*, *A. barbirostris*, *A. hyrcanus*, *A. jamesi*, *A. karwari*, *A. kochi*, *A. leucosphyrus*, *A. splendidus*, *A. subpictus*, *A. tessellatus* and *A. vagus*, wherever they have been dissected, have not been found with salivary-gland infections, or have been so infected only in very small numbers. These may be vectors of practical importance in communities in which they are very dense, and where environmental conditions influencing their feeding are conducive to their becoming vectors. In the case of *A. aitkeni*, *A. gigas*, *A. majidi*, *A. pallidus*, *A. theobaldi* and *A. varuna* insufficient data are at

* Excluding the series of 91 dissected by Winoto (1919).

present available from which to draw conclusions. Of all the species that are found constantly infected, the rates differ considerably in different localities, but it would appear not improbable that this difference can be accounted for almost entirely by zoophilism. *A. maculatus* is a vector of considerable importance in Malaya when the cattle population is comparatively small. *A. annularis* and *A. philippinensis,* which are markedly zoophilic, are infected in Assam where cattle are abundant and closely associated with man, to a lesser degree than elsewhere. Such considerations would seem strongly to support the view that the receptivity of any species to gametocytes is constant for that species and that there is no fundamental difference between the importance of a species as a potential vector in different localities.

If this be the case, it should be possible on some experimental basis to find an 'index of receptivity to infection' for each species of *Anopheles* to each species of *Plasmodium.* Should such a receptivity index be discoverable and be found to be constant for each species, then the relative importance of any species as a vector of malaria in any community could probably be readily calculated. A formula could be constructed based on this and on certain other factors which could be determined on a malaria survey of the particular locality without undertaking the formidable task of investigating the infectivity by dissection of naturally caught mosquitoes. The other important factors which would have to be determined are the androphilic index of each species in the community and the relative density of the species. A further factor which might have to be taken into account is the average length of life or number of blood feeds taken but our present knowledge of these factors is not sufficient upon which to make any estimation of their relative importance.

It may be found possible to determine the relative receptivity to infection on the basis adopted by Green (1931), by feeding at the same time different species on a gametocyte carrier, but as has been previously mentioned the 'quality' of the gametocyte differs widely in different cases. It is suggested that a profitable line of research, with a view to determining an index, might be by mass experimental feeding. For instance, feeding 200 laboratory-bred mosquitoes of two or more species on 200 human beings, taken at random from a community in which such data as the degree of malaria and relative prevalence of different species of malarial parasites are known. Experiments on these lines in different localities might prove exceedingly valuable. The average longevity of individual anophelines in different localities might be ascertained by the co-operation of workers in different localities, batches of mosquitoes being confined and subjected to conditions simulating nature as closely as possible.

Finally, stress is laid on the importance of determining the relative density in every community. The figures in Table II do not represent relative densities. The commoner species were discarded when sufficiently large numbers had been examined, and the rarer and more important species were particularly sought for. Of the work done in Assam, the figures published in the 1933 Quarterly Reports of the Assam Medical Research Society will probably afford the best basis for comparison. The information which is actually required is the relative number of female adults of each species which visits the community under consideration for the purpose of taking a blood meal. Such figures are, however, not available in sufficiently large numbers for comparison of different communities in the Province (Assam). In 1933, the Assam Medical Research

Society workers collected larvæ and adults from 16 centres in the plains and from a number of hill districts. Dr. Savage has stated in a personal communication to the writer that no instructions were given for selective collection so the numbers from each area might be taken as roughly representing the numerical prevalence of each species in that area. Table IV has been compiled from Savage's Report and shows the total number of larvæ and adults of *A. annularis, A. culicifacies, A. jeyporiensis, A. maculatus* (together with *A. maculatus* var. *willmori*), *A. minimus, A. philippinensis, A. ramsayi, A. stephensi* and *A. umbrosus* collected in the second and third quarters of 1933 from each of the following centres :—

Darrang, Mangaldai; Kamrup, Gauhati; Khasi Hills, Shillong; Sibsagar, Jorhat, and the total for the whole province has been calculated.

It is fully appreciated that these figures of relative densities may be widely different from the actual densities of female adults in the districts mentioned, but they serve to demonstrate the great importance of attempting to estimate densities accurately.

If these figures and the Assam salivary-gland infection rates represent the true position, then the product of these two figures will represent the relative number of insects with salivary-gland infections that would be found amongst communities in the areas concerned. These products have been calculated and are shown in column 3 of Table IV, the salivary-gland infection rate being based on the Ross Institute and Assam Medical Research Society dissections. It will be seen that, considering Assam as a whole, *A. minimus* is more frequently infected than all other species, and is in great preponderance in Mangaldai. In Gauhati it will be noticed that *A. minimus* are rarer, and infected *A. annularis* are in preponderance. In Shillong infected *A. maculatus* are much more frequent than *A. minimus*, and in Sibsagar *A. culicifacies* would appear to be a vector of some importance as well as *A. minimus*. In considering these results it must be mentioned that such figures, even if based on adequate data, would not represent the relative importance of each as a vector, as the androphilic factor must be taken into account. These figures, nevertheless, seem to demonstrate that a species cannot be neglected as a vector because its infectivity rate is low. Although *A. philippinensis* has not yet been found with a salivary-gland infection in Assam, the findings would lead one to expect that there is probably a low salivary-gland infectivity rate, and from its great numerical prevalence it may be a vector of importance in some communities. Similarly, *A. umbrosus*, and *A. jeyporiensis*, although extremely rare, may be important vectors in such communities as are adjacent to their breeding sites.

SUMMARY.

(*a*) The results of the investigation into blood feeding habits of some anopheline mosquitoes in the tea districts of Assam and Northern Bengal, carried out by observers working in conjunction with the Ross Institute of Tropical Hygiene, have been compared with the findings of observers who have investigated this habit of the same species in other parts of the Oriental region.

(*b*) The results of 106,272 dissections of anopheline mosquitoes in Assam and Northern Bengal, representing the total of the work done on infectivity up to the end of 1934 by Ramsay and his collaborators, are recorded, and are compared with the infectivity findings of the Assam Medical Research Society.

(*c*) The results of the infectivity survey carried out by these two organisations are compared with the infectivity surveys in other parts of the Oriental region in which the same species have been investigated.

(*d*) The reason for the wide variation of the results of experimental infection of mosquitoes with malaria is discussed.

(*e*) The following conclusions are drawn from a critical analysis of the collected data :—

1. That, in any species of anopheline which cannot be divided on morphological differences into sub-species or varieties, the biological and physiological characters, including such characters as feeding preference and receptivity to malarial infection, are fundamentally identical in whatever country or district it is breeding.
2. That variation of the androphilic index in batches of mosquitoes of a single species, collected from different communities, is dependent on the relative availability of the blood food of preference in that community.
3. That variation in the infectivity index in batches of mosquitoes of a single species, collected in different countries or districts, is dependent on differences in environmental conditions.
4. That a most important environmental factor, in accounting for variation in the infectivity index of a single species, is the relative availability of the blood food of preference.
5. That other possible factors are climate, affecting the average longevity of the species, and variation in the potency of the prevailing strain of plasmodium in different localities to infect mosquitoes, each strain conceivably having its own selective action on each species of anophelines.
6. Stress is laid on the great importance of estimating the relative densities of potential vectors amongst any community in which control by selective anti-mosquito measures is undertaken.
7. It is suggested that a most profitable line for further research would be mass experimental feeding of batches of laboratory-hatched mosquitoes on malarious communities. This would be undertaken with a view to determining the 'receptivity index' of each species to plasmodial infection.
8. It is suggested that further research is needed on the longevity of species under natural conditions in different areas, and also on the average number of blood meals ingested.

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ADDENDUM.

Since preparing Table III, 'Aids to the Identification of Anopheline Imagines in Malaya' by B. A. R. Gater, 1935, in which some 33,000 dissections by workers in Malaya are quoted, has come to the author's hand. Gater has collected a very considerable amount of work to add to the somewhat meagre totals of Malayan dissections available for Covell in 1931.

The findings are nearly all consistent with the conclusions arrived at in this paper. Two or three points, however, call for special notice and comment.

A. barbirostris van dér Wulp : In addition to the Malayan dissections included in Table III, Gater reports 2,072. Of these Hacker and Hodgkin contribute series totalling 1,098 dissections, 22 gut infections and 16 gland infections are reported (a sporozoite infectivity rate of 1·5 per cent approximately). Of the remaining series collected by Gater and those contained in Table III which together total 2,972 not a single gland is reported positive.

Possibly further work on *A. barbirostris* in Malaya may show that it can be divided into varieties which have different degrees of receptivity to Malaria.

A. hyrcanus var. *nigerrimus* Giles : Gater has collected records of 1,285 in addition to the 19,842 dissections in Table III. Of the total 21,127 the only positives recorded are in two series by Hodgkin, totalling 407 in which he reports 10 gut and 5 gland.

A. karwari James : Gater has collected records of 3,625 dissections in addition to the 15,865 collected in Table III. Of the total 19,490 the only positives recorded are 1 gut and 2 glands in two series by Hodgkin totalling 3,433.

A. maculatus Theo. : In addition to those collected in Table III Gater has collected 11,295 (in which details as to guts and glands are recorded) in these series 82 guts and 129 glands are recorded as positive giving a sporozoite infectivity rate of 1·1 per cent approximately.

In view of the zoophilic nature of *A. maculatus* it is interesting to note the specimens collected from the tea population of Assam where cattle are closely associated with man the sporozoite infectivity rate is 0 0 per cent in 7,666 dissections; in specimens collected from the urban populations of Assam where cattle are plentiful but are less intimately associated with man, the sporozoite infectivity rate is 0·2 per cent approximately in 3,558 dissections; and in specimens collected in Malaya where cattle are rare the sporozoite rate is 1·1 per cent approximately in 11,295 dissections.

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TABLE I.

Species examined.	Total number examined.	Androphilic indices, per cent.
A. minimus	622	85·7
A. leucosphyrus	102	75·5
A. karwari	311	16·4
A. philippinensis	343	6·4
A. maculatus	130	5·4
A. hyrcanus var. *nigerrimus*	453	3·8
A. kochi	213	3·8
A. subpictus	326	1·8
A. annularis	192	1·6
A. vagus	593	0·8
A. splendidus	214	..

TABLE II.

Species.	Number dissected.	Number with guts only positive.	Number with glands only or gut and glands positive.	Total infected.	Total infectivity rate, per cent.	Sporozoite infectivity rate, per cent.
A. aconitus Donitz, 1902	2,738	..	..	..	..	..
* *A. aitkeni* James, 1903	15	..	..	..	..	..
A. annularis Van der Wulp, 1884.	1,983	..	1	1	0·05	0·05
† *A. barbirostris* Van der Wulp, 1884.	661	..	..	..	..	..
A. culicifacies Giles, 1901.	322	2	2	4	1·2	0·6
A. fluviatilis James, 1902.	127	..	1	1	0·8	0·8
A. hyrcanus var. *nigerrimus* Giles, 1900.	15,590	..	..	..	..	..
A. jamesi Theo., 1901	935	..	..	..	..	..
‡ *A. jeyporiensis* James, 1902.	2,424	1	..	1	0·04	..
A. karwari James, 1903	15,550	..	..	..	..	..
A. kochi Donitz, 1901	3,900	4	..	4	0·1	..
A. leucosphyrus Donitz, 1901.	504	..	..	..	..	..
A. maculatus Theo., 1901.	7,666	1	..	1	0·01	..
A. majidi McCombie Young and Majid, 1928.	17	..	..	..	..	..

* May include specimens of var. *bengalensis* or *A. insulaeflorum.*
† May include specimens var. *ahomi.*
‡ Including specimens probably of var. *candidiensis.*

TABLE II—*concld.*

Species.	Number dissected.	Number with guts only positive.	Number with glands only or gut and glands positive.	Total infected.	Total infectivity rate, per cent.	Sporozoite infectivity rate, per cent.
A. minimus Theo., 1901.	21,048	268	513	781	3·7	2·4
A. philippinensis Ludlow, 1902.	12,464	..	..	..	..	..
A. ramsayi Covell, 1927.	289	..	1	1	0·3	0·3
A. splendidus Koidzumi, 1920.	1,128	..	..	..	..	..
A. stephensi Liston, 1901.	6	..	..	..	..	..
A. subpictus Grassi, 1899.	925	..	..	..	..	..
A. tessellatus Theo., 1901.	123	..	..	..	..	..
A. theobaldi Giles, 1901.	5	..	..	..	..	..
A. umbrosus Theo., 1903.	3	..	..	..	..	..
A. vagus Donitz, 1902	17,831	..	..	..	..	..
A. varuna Iyengar, 1924.	17	..	..	..	..	..

TABLE III.

	Number dissected.	Guts infected.	Glands infected.	Sporozoite infectivity rate, per cent.
A. aconitus Donitz, 1902.				
Ross Institute	2,738	0	0	
Assam Medical Research Society	49	0	0	
Assam (total)	2,787	0	0	0·0
Rest of India	..	..	..	
Burma	300	1	0	
Federated Malay States ..	890	2	0	
Dutch East Indies	2,173	3	7	
Tonkin	385	2	0	
TOTAL ..	6,535	8	7*	0·1

* Seven glands positive in a series of 91 dissected by Winoto (1919).

TABLE III—*contd.*

	Number dissected.	Guts infected.	Glands infected.	Sporozoite infectivity rate, per cent.
A. aitkeni James, 1903, also var. *bengalensis* and *A. insulaeflorum*.				
Assam (Ross Institute) ..	15	0	0	0·0
A. annularis Van der Wulp, 1884.				
Ross Institute	1,983	0	1	
Assam Medical Research Society	1,278	0	0	
Assam (total)	3,261	0	1	0·03
Rest of India	11,183	9	15	
Burma	1,409	3	5	
Federated Malay States ..	46	1	0	
Dutch East Indies	261	0	0	
Ceylon	47	0	0	
Philippines	194	0	0	
Tonkin	346	0	0	
TOTAL ..	16,747	13	21	0·1
A. barbirostris Van der Wulp, 1884, and *A. barbirostris* var. *ahomi* Chowdhury, 1929.				
Ross Institute	661	0	0	
Assam Medical Research Society	419	0	0	
Assam (total)	1,080	0	0	0·0
Rest of India	23	0	0	
Burma	239	0	0	
Federated Malay States ..	443	1	0	
Ceylon	108	0	0	
Philippines	60	0	0	
Tonkin	45	0	0	
TOTAL ..	1,998	1	0	0·0
A. culicifacies Giles, 1901.				
Ross Institute	322	2	2	
Assam Medical Research Society	19	0	0	
Assam (total)	341	2	2	0·6
Rest of India	8,425	215	63	
Burma	615	6	1	
Ceylon	4,266	62	113	
TOTAL ..	13,647	285	179	1·3
A. fluviatilis James, 1902.				
Assam (Ross Institute) ..	127	0	1	0·8
Rest of India	1,174	7	5	
Ceylon	114	0	0	
TOTAL ..	1,415	7	6	0·4

TABLE III—*contd.*

	Number dissected.	Guts infected.	Glands infected.	Sporozoite infectivity rate, per cent.
A. gigas Giles, 1901.				
Assam (Assam Medical Research Society).	7	0	0	0·0
A. hyrcanus var. *nigerrimus* Giles, 1900.				
Ross Institute	15,590	0	0	
Assam Medical Research Society	3,758	0	0	
Assam (total)	19,348	0	0	0·0
Rest of India	285	0	0	
Burma	15	0	0	
Federated Malay States ..	84	0	0	
Ceylon	33	0	0	
Philippines	77	0	0	
TOTAL ..	19,842	0	0	0·0
A. jamesi Theo., 1901.				
Assam (Ross Institute) ..	935	0	0	0·0
Ceylon	16	0	0	
Burma	35	0	0	
TOTAL ..	986	0	0	0·0
A. jeyporiensis James, 1902, and *jeyporiensis* var. *candidiensis* Koidzumi, 1924.				
Ross Institute	2,424	1	0	
Assam Medical Research Society	320	0	0	
Assam (total)	2,744	1	0	0·0
Rest of India	1,988	3	0	
Tonkin	826	4	2	
TOTAL ..	5,558	8	2	0·4
A. karwari James, 1903.				
Assam (Ross Institute) ..	15,550	0	0	0·0
Rest of India	49	0	0	
Burma	53	0	0	
Federated Malay States ..	80	0	0	
Dutch East Indies	96	0	0	
Philippines	27	0	0	
Tonkin	10	0	0	
TOTAL ..	15,865	0	0	0·0
A. kochi Donitz, 1901.				
Ross Institute	3,900	4	0	
Assam Medical Research Society	718	0.	0	
Assam (total)	4,618	4	0	0·0
Federated Malay States ..	83	0	0	
Dutch East Indies	1,531	0	0	
Tonkin	120	0	0	
TOTAL ..	6,352	4	0	0·0

TABLE III—*contd.*

	Number dissected.	Guts infected.	Glands infected.	Sporozoite infectivity rate, per cent.
A. leucosphyrus Donitz, 1901.				
Ross Institute	504	0	0	
Assam Medical Research Society	6	0	0	
Assam (total)	510	0	0	0·0
Rest of India	9	0	0	
Dutch East Indies	28	0	0	
North Borneo	17	0	0	
TOTAL ..	564	0	0	0·0
A. maculatus Theo., 1901.				
Ross Institute	7,666	1	0	
Assam Medical Research Society	3,558	9	7	
Assam (total)	11,224	10	7	0·06
Rest of India	71	0	0	
Burma	13	1	0	
Federated Malay States ..	168	3	5	
Dutch East Indies	638	12	0	
Ceylon	21	0	0	
Tonkin	90	1	1	
TOTAL ..	12,225	27	13	0·1
A. maculatus var. *willmori* James, 1903.				
Assam (Assam Medical Research Society).	845	1	0	0·0
A. majidi McCombie Young and Majid, 1928.				
Assam (Ross Institute) ..	17	0	0	0·0
A. minimus Theo., 1901.				
Ross Institute	21,048	268	513	
Assam Medical Research Society	3,755	171	147	
Assam (total)	24,803	439	660	2·7
Rest of India	278	0	6	
Burma	350	9	0	
Philippines	21,707	181	117	
Tonkin	1,830	41	15	
Cochin China	63	2	3	
TOTAL ..	49,031	672	801	1·6
A. pallidus Theo., 1901.				
Assam (Assam Medical Research Society).	73	0	0	0·0
Rest of India	1,570	0	3	
TOTAL ..	1,643	0	3	0·2

TABLE III—*contd.*

	Number dissected.	Guts infected.	Glands infected.	Sporozoite infectivity rate, per cent.
A. philippinensis Ludlow, 1902.				
Ross Institute	12,464	0	0	
Assam Medical Research Society	2,985	4	0	
Assam (total)	15,449	4	0	0·0
Rest of India	1,451	3	27	
Burma	676	4	2	
Tonkin	592	0	0	
TOTAL ..	18,168	11	29	0·2
A. ramsayi Covell, 1927.				
Ross Institute	289	0	1	
Assam Medical Research Society	635	0	0	
Assam (total)	924	0	1	0·1
Rest of India	222	0	0	
TOTAL ..	1,146	0	1	0·1
A. splendidus Koidzumi, 1920.				
Assam (Ross Institute) ..	1,128	0	0	0·0
Rest of India	315	0	0	
Tonkin	81	0	0	
TOTAL ..	1,524	0	0	0·0
A. stephensi Liston, 1901.				
Assam (Ross Institute) ..	6	0	0	0·0
Rest of India	2,779	128	54	
TOTAL ..	2,785	128	54	1·9
A. subpictus Grassi, var. *indefinitus* Ludlow and var. *malayensis* Hacker.				
Ross Institute	925	0	0	
Assam Medical Research Society	314	0	0	
Assam (total)	1,239	0	0	0·0
Rest of India	6,257	0	0	
Burma	113	0	0	
Federated Malay States ..	102	0	0	
Dutch East Indies	668	1	0	
Ceylon	924	0	0	
Philippines	401	0	0	
Tonkin	4	0	0	
TOTAL ..	9,708	1	0	0·0

TABLE III—*concld.*

	Number dissected.	Guts infected.	Glands infected.	Sporozoite infectivity rate, per cent.
A. tessellatus Theo., 1901.				
Ross Institute	123	0	0	
Assam Medical Research Society	27	0	0	
Assam (total)	150	0	0	0·0
Rest of India	116	0	0	
Federated Malay States ..	167	0	0	
Dutch East Indies	1,751	1	0	
Tonkin	63	0	0	
TOTAL ..	2,247	1	0	0·0
A. theobaldi Giles, 1901.				
Assam (Ross Institute) ..	5	0	0	0·0
A. umbrosus Theo., 1903.				
Assam (Ross Institute) ..	3	0	0	0·0
Federated Malay States ..	303	1	6	
Dutch East Indies	126	6	0	
Borneo	130	0	1	
TOTAL ..	562	7	7	1·2
A. vagus Donitz, 1902, and var. *limosus*.				
Ross Institute	17,831	0	0	
Assam Medical Research Society	3,520	0	0	
Assam (total)	21,351	0	0	0·0
Rest of India	4,692	0	0	
Burma	152	0	0	
Federated Malay States ..	787	0	0	
Dutch East Indies	107	0	0	
Andamans	100	0	0	
Tonkin	2,625	1	1	
TOTAL ..	29,814	1	1	0·003
A. varuna Iyengar, 1924.				
Assam (Ross Institute) ..	17	0	0	0·0
Rest of India	59	1	0	
TOTAL ..	76	1	0	0·0

Table IV.

Area from which specimens were collected.	Darrang, Mangaldai.		Kamrup, Gauhati.		Khasi Hills, Shillong.		Sibsagar, Jorhat.		Total for whole province.	
Species.	Relative numerical prevalence.	Relative number with salivary-gland infection.	Relative numerical prevalence	Relative number with salivary-gland infection	Relative numerical prevalence.	Relative number with salivary-gland infection.	Relative numerical prevalence.	Relative number with salivary-gland infection.	Relative numerical prevalence.	Relative number with salivary-gland infection.
A. annularis ..	162	4·9	637	19·1	273	8·2	270	8·1	10,560	316·8
A. culicifacies ..	0	0·0	6	3·6	12	7·2	105	63·0	762	457·2
A. jeyporiensis ..	0	..	0	..	9	..	1	..	125	..
A. maculatus (and var. *willmori*).	0	0·0	6	0·4	6.185	371·1	83	4·9	9,717	583·0
A. minimus ..	136	367·2	2	5·4	31	83·7	53	143·1	1.749	4.722·3
A. philippinensis	0	..	390	..	0	..	3.469	..	7,190	..
A. ramsayi ..	0	0·0	386	38·6	0	0·0	0	0·0	465	46·5
A. stephensi ..	0	..	0	..	0	..	0	..	5	..
A. umbrosus ..	0	..	0	..	0	..	1	..	17	..
Total of all species.	1,157	..	3,078	..	9.934	..	14.322	..	89.471	..

The 'Relative Number with Salivary Gland Infection' are the products of the 'Relative Numerical Prevalence' and the 'Infectivity Rates' for Assam which are taken from Table III and are as follows:—

A. annularis	0·03	*A. minimus*	2·7
A. culicifacies	0·6	*A. ramsayi*	0·1
A. maculatus	0·06		

Records of the Malaria Survey of India, **6**, **2**, *June*, *1936*.

RELATION OF THE SALINITY OF THE BREEDING PLACES OF *ANOPHELES SUNDAICUS* WITH THE ENDEMICITY OF MALARIA IN THE SUBURBAN AREAS OF CALCUTTA.

BY

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[12th March, 1936.]

INTRODUCTION.

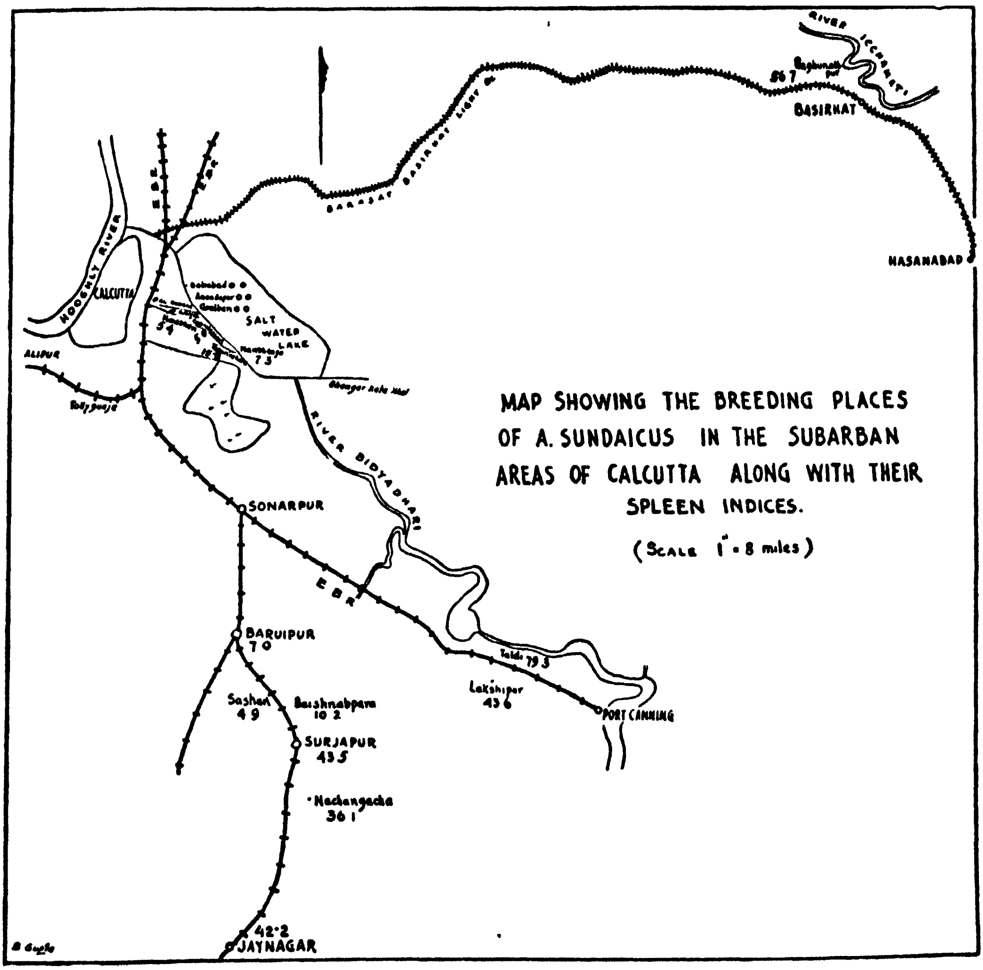
WITHIN recent years, the distribution of *A. sundaicus* in the suburban areas of Calcutta has become more widespread. This species is normally a brackish-water breeder but is able to adapt itself to a considerable extent to waters of varying concentration of salinity. The lowest limit of salinity recorded in breeding places of *A. sundaicus* was 7·8 parts per 100,000 parts, whereas the upper limit was 2,675 parts per 100,000 parts (Neogi, 1936).

This species has acquired notoriety, because it is a good carrier of parasites during local outbreaks of malaria in an epidemic form. The natural rates of infectivity in these insects, as found on several instances by the Bengal Public Health Department, are given below: (1) During the Budge-Budge epidemic in October 1930, the rate was as high as 23·4 per cent (Iyengar, 1931). (2) In a similar outbreak of malaria in the salt-lakes region at Chingrighata, the rate of infectivity was found to be 20·0 per cent. (3) The infection rate amongst the specimens of this species collected from trains, coming to Majerhat from Fulta, was as high as 7·0 per cent in 1931-32. Laurel (1934) asserts that his observation by precipitin test with fresh-water-breeding *ludlowi* showed positive reaction for cattle blood but not for human. On the other hand salt water '*ludlowi*' (*sundaicus*) showed positive avidity for human blood.

The present investigation was undertaken to ascertain by statistical facts what influence *A. sundaicus* (a species akin to *A. ludlowi*), when bred out in waters of varying degrees of salinity, has upon the endemicity of malaria in any particular locality. To this point, the period of observation, with reference to the suburban areas of Calcutta, was confined to the month of December 1935, and limited to a number of villages where *A. sundaicus* had established

itself more or less permanently. To do away with such discrepancies as might creep in through unavoidable circumstances, such as changes in weather and environment from month to month, which may affect the natural findings of the breeding of *A. sundaicus,* the salinity factor and the spleen indices of the

MAP.



villages, the entire observation was strictly limited to the period of one month as stated above. The three variable factors which have been put forward for discussion are as follows :—

SPLEEN RATE.

The endemicity of malaria in a locality may be fairly measured from the observed spleen census amongst children. Thus, in the present instance, to estimate the endemicity or static condition of malaria of the various villages under consideration, the spleen rates were recorded among the children. The results with reference to each village are shown in Table I.

TABLE I.

Area.	Villages.	Number of children examined.	Number with enlarged spleen.	Spleen index.
Salt lakes ..	Nuniavery	37	2	5·4
" ..	Kaptenvery	20	1	5·0
" .	Tapuriaghata	19	3	15·8
" ..	Naobhanga	27	2	7·3
" ..	Goalbari	28	0	0·0
" ..	Anandapur	34	0	0·0
" ..	Dattabad	24	0	0·0
Canning P. S. ..	Lakshipur	55	24	43·6
" ..	Taldi	63	50	79·3
Jaynagar P. S. ..	Jaynagar	45	19	42·2
Baruipur P. S. ..	Baruipur	100	7	7·0
" ..	Nachangacha	36	13	36·1
" ..	Baishnabpara	39	4	10·2
" ..	Sashan	61	3	4·9
" ..	Surjapur	46	20	43·5
Bashirhat P. S. ..	Raghunathpur	37	21	56·7

AVERAGE SALINITY OF THE WATER IN THE BREEDING PLACES.

This has been investigated separately for each of the areas. The salinity of the water in breeding places where larvæ has been determined and is expressed in parts per 100,000 parts. Table II shows the results.

TABLE II.

Villages.	Chloride content per 100,000 parts of individual samples.	Average salinity
Nuniavery ..	182, 345, 177, 164, 152, 164, 94, 220, 192, 312, 102, 87, 196, 194, 310, 152, 192, 159.	188·56
Kaptenvery ..	196, 271, 111, 145, 295, 97, 225, 149, 99, 107, 229, 142, 282.	180·62
Tapuriaghata ..	288, 426, 75, 403.	298·00
Naobhanga ..	126, 224.	175·00
Goalbari ..	198, 202, 44, 170, 15, 140, 203, 46, 31, 21, 256.	120·54
Anandapur ..	104, 202, 240, 52, 52, 126.	129·33
Dattabad ..	66, 140, 150, 164.	130·00
Lakshipur ..	112, 74, 78, 124, 118, 56.	93·97
Taldi ..	824, 450, 425, 690, 110, 390, 112, 140, 320, 568, 182, 415, 498, 277, 770, 225, 720, 220, 120, 132, 466, 330, 536.	387·74
Jaynagar ..	82, 80.	81·00
Baruipur ..	120, 131, 119, 118, 121, 124, 126.	122·71
Nachangacha ..	56, 58.	57·00
Baishnabpara ..	124, 122, 128, 130, 120, 128, 121, 124, 124, 123, 124, 14, 115, 122.	115·64
Sashan ..	114, 118, 138, 120, 112, 114, 136, 118, 138.	122·67
Surjapur ..	46, 58, 36, 60, 86, 70, 119, 79, 88.	77·33
Raghunathpur ..	153, 155, 340, 73, 46, 13, 73.	121·86

INTENSITY OF BREEDING.

The number of mosquito-breeding places, which have been detected in each village, is given below. The frequency of the breeding of *A. sundaicus* has been shown by its ratio to the total number of random samplings (Table III).

TABLE III.

Villages.	Number of samples examined.	Samples showing *A. sundaicus.*	Percentage.
Nuniavery ..	34	18	53
Kaptenvery ..	31	13	42
Tapuriaghata ..	23	4	17
Noabhanga ..	17	2	12
Goalbari ..	57	11	19
Anandapur ..	24	6	25
Dattabad ..	14	4	29
Lakshipur ..	14	6	43
Taldi ..	28	23	82
Jaynagar ..	9	2	22
Baruipur ..	10	7	70
Nachangacha ..	8	2	25
Baishnabpara ..	16	14	87
Sashan ..	9	9	100
Surjapur ..	20	9	45
Raghunathpur .	17	7	41

DISCUSSION ON FACTORS INFLUENCING THE INCIDENCE OF MALARIA IN THE ABOVE-MENTIONED VILLAGES.

In the above paragraphs the three variables, namely the spleen rates, the average salinity and the relative number of breeding places, with reference to the villages under consideration, have been recorded. For the purpose of determining the coefficient of correlation between these several factors Table IV has been prepared.

TABLE IV.

Villages.	Spleen rate. 1	Average salinity per 100,000 parts. 2	Percentage of samples showing *A. sundaicus.* 3
Nuniavery ..	5·4	188·56	53
Kaptenvery ..	5·0	180·62	42
Tapuriaghata ..	15·8	298·00	17
Noabhanga .	7·3	175·00	12
Goalbari ..	0·0	120·54	19
Anandapur ..	0·0	129·33	25
Dattabad ..	0·0	130·00	29
Lakshipur ..	43·6	93·67	43
Taldi ..	79·3	387·34	82
Jaynagar ..	42·2	81·00	22
Baruipur .	7·0	122·71	70
Nachangacha .	36·1	57·00	25
Baishnabpara ..	10·2	115·64	87
Sashan ..	4·9	122·67	100
Surjapur ..	43·5	71·33	45
Raghunathpur ..	56·7	121·86	41

The standard deviations of the above three variables have been calculated to be as follows :—

$\sigma_1 = 23{\cdot}614 \pm 2\ 814$, $\sigma_2 = 82\ 719 \pm 9\ 860$, $\sigma_3 = 26{\cdot}227 \pm 3{\cdot}126$,

and the coefficients of correlation between each one of the others have been calculated to be as follows :—

$R_{12} = 0{\cdot}246 \pm 0{\cdot}175$, $R_{13} = 0{\cdot}029 \pm 0{\cdot}186$, $R_{23} = 0{\cdot}166 \pm 0{\cdot}181$.

INTERPRETATION OF FINDINGS.

The coefficient of correlation between the average salinity of the breeding places of *A. sundaicus*, and the spleen rate amongst children in any locality, that is R_{12}, is $0\ 246 \pm 0\ 175$. This is low and insignificant. It means that the breeding of *A. sundaicus* in waters of varying concentration of salinity does not bring about any change in the susceptibility of malarial infection amongst these insects, which may influence the endemicity of malaria, and be reflected in the spleen rates of the locality.

Similarly the coefficient of correlation between the spleen rate and the frequency of breeding places of *A. sundaicus* (R_{13}) has not been found to be significant. It may be noted that the endemicity of malaria in an area depends, as a rule, upon the density of anopheline population, which can carry malaria parasites. In this particular instance, however, the presence of *A. sundaicus*, which has often been found to carry malaria on many occasions in localised outbreaks of the disease, does not appear to show any relation with malaria, even when the breeding becomes more intense.

Lastly, the coefficient of correlation between the average salinity and the frequency of breeding places of *A. sundaicus*, that is R_{23}, does not reveal any significant fact. This means that the varying concentration of salinity in the breeding places of *A. sundaicus* does not determine the intensity of its breeding in that locality.

As both the factors of salinity and the amount of breeding may each have an individual influence upon the malariousness of a locality, an attempt has been made to ascertain their individual influence by the help of partial correlation. In other words, what is the coefficient of correlation between the spleen rate and the average salinity, when the frequency of breeding places remains constant ? Similarly, what is the coefficient of correlation between the spleen rate and the intensity of breeding of *A. sundaicus*, when salinity remains constant ?

The calculations have been made by Yule's method of partial correlation the formula being

$$R_{12\cdot34\ldots n} = \frac{R_{12\cdot34\ldots(n-1)} - R_{1n\,34\ldots(n-1)} \times R_{2n.34(\ldots n-1)}}{\left\{1 - R^2_{1n\,34\ldots(n-1)}\right\}^{\frac{1}{2}} \left\{1 - R^2_{2n.34\ldots(n-1)}\right\}^{\frac{1}{2}}}$$

We find, (1) the coefficient of correlation between the spleen rate and average salinity, keeping the frequency of breeding constant, is :—$R_{12\cdot3} = 0\ 246 \pm 0\ 175$, which is positive, low, and insignificant,

(2) the coefficient of correlation between the spleen rate and the intensity of breeding, keeping the salinity factor constant, is :—$R_{13\cdot2} = 0{\cdot}001 \pm 0{\cdot}186$, which is not significant.

SUMMARY.

(1) Laurel (1934) asserts, *A. ludlowi* breeding in sweet waters acquired an avidity for cattle blood! On the other hand salt-water-breeding *ludlowi* (*sundaicus*) shows an avidity for human blood.

(2) The coefficients of correlation between the three variables, namely, (*i*) spleen rate, (*ii*) average salinity and (*iii*) number of breeding places, have been determined by statistical method and the results obtained are (*i*) $R_{12} = 0.246 \pm 0.175$, which is low, positive and insignificant; (*ii*) $R_{13} = 0.029 \pm 0.186$ which is low, positive and insignificant; and (*iii*) $R_{23} = 0.166 \pm 0.181$ which is low, positive and insignificant.

(3) Similarly the coefficients of correlation between the (*i*) spleen rate and the average salinity and (*ii*) the spleen rate and frequency of breeding of *A. sundaicus*, have been deduced by the method of partial correlation keeping the third factor constant. The results are as follows :—

$R_{12 \cdot 3} = 0.246 \pm 0.175$ low, positive and insignificant.
$R_{13 \cdot 2} = 0.001 \pm 0.186$ „ „ „ „

(4) Increased frequency of breeding places of *A. sundaicus* or the amount of chloride contents in them, seems to have no association with the endemicity of malaria in the suburban areas of Calcutta.

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EPIDEMIC MALARIA IN MADRAS PRESIDENCY.

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CONTENTS.

I. INTRODUCTION.

IN his study of the epidemiology of malaria, Gill (1914) proposed the following classification of its manifestations and defined their exact significance:

(a) an endemic disease—
  (i) in the tropics,
  (ii) in the sub-tropics.

(*b*) an epidemic disease—
(*i*) localised,
(*ii*) generalised,
(*iii*) fulminant.

Tropical malaria was meant to denote the occurrence of malaria in areas where, owing to the tropical nature of the climate, malarial infections may occur throughout the year. Sub-tropical malaria on the other hand was held to imply the occurrence of malaria in areas where malarial infection can only be contracted during a portion of the year.

Epidemic malaria was considered to connote the occurrence in endemic areas of an exaggeration of the normal incidence of the disease, together with a moderate increase in its mortality and, depending upon the area involved, it was divided into localised and generalised epidemics. For malarial outbreaks which assume almost pandemic proportions, together with a virulence greatly in excess of the normal, Gill adopted Christopher's term 'fulminant malaria' in preference to Celli's appellation of 'pandemic malaria'. Since the greatest intensity of such epidemics affects those communities which show a high degree of endemicity with little diffusion beyond their endemic limits, Gill subsequently adopted the term 'regional epidemics'.

According to Justice [quoted by Gill (1914)] severe epidemic malaria is unknown in Madras. Its comparative rarity in Madras is put forward by Gill in support of the validity of his theory of genesis of epidemics which ascribes such occurrences to a loss of equilibrium between infection and resistance. In a tropical climate like that of Madras, there will be constancy of infection which will engender constant resistance and hence a reasonable equilibrium established between the two.

In this paper it is proposed to discuss the prevalence of malaria epidemics in the Madras Presidency. Some of these were associated with as high a mortality as the 'regional epidemics' of the Punjab, although they have very many points of difference such as their cyclical and seasonal periodicity, 'wave form', toxicity, specific age incidence of mortality, effects on fecundity, etc. A brief reference will first be made to the previous records of the prevalence of epidemic malaria in the different parts of the province. Later the characteristics of the two recent epidemics of malaria of severe intensity, which prevailed in Madakasira taluk of Anantapur district, and in Harpanahalli, Hadagalli and Kudligi taluks of Bellary district, will be described in greater detail.

II. PREVIOUS RECORDS OF EPIDEMIC MALARIA.

Horne (1913) reported the occurrence of an epidemic of malaria in 1909-10 and again in 1910-11 in Cuddapah district and he quoted the figures shown in Table I.

TABLE I.

Average.	1905–09.	1910.	1911.
Birth rate	26·7	21·3	21·0
Death rate	22·5	32·7	24·5
Infantile mortality rate	159·7	232·9	155·5

'In 1909-10, the epidemic involved five taluks in the south-east corner of the district with its centre at Rayachoti (hill taluk) whose epidemic figure was 5 9 and spread to a slight extent eastwards and to the adjoining district of Nellore. It commenced simultaneously in all the five taluks in October, reached its height in December and ceased in the following March. The northern taluks *with the exception of Cuddapah** were not involved at all. The 1910-11 epidemic affected the northern taluks mainly *with its centre at Cuddapah**—epidemic figure 4 3. This time the hill taluks with one exception escaped. In both the epidemics, almost all the taluks affected showed an abnormally heavy rainfall that year. Deaths were mainly among children. In Rayachoti taluk in December 1909 and January 1910 the death rate among children from 1 to 10 years was 30 times normal, while that among adults in each decennium 20 to 50 was 3 times normal. Still more significant is the effect of these epidemics on the births as shown in Table II.

TABLE II.

Births.

	Average (1905-09).	1910.	1911.
Vayalpad (involved 1909-10) ..	3,366	1,812	3,318
Cuddapah (involved both years) ..	3,266	2,354	2,326
Siddhout (both years)	1,804	1,337	1,428

'Cuddapah has an average rainfall of 28 inches which occurs mainly from July to September, mean temperature 84°F., mean humidity between 60 and 70 per cent. The country is liable to floods, the cultivation is mostly dry and the chief crop is cholam' (Horne, 1913).

Referring to this epidemic, Gill (1914) argues, and quotes the *Gazetteer* in support of his argument, that the meteorological conditions recorded in Cuddapah town, which go to show that the period of infection is not likely to be interrupted, are not necessarily the same in the rural areas in the district which are reported to have very large variations in climatic conditions—variations which tend to interrupt the period of infection and hence disturb the equilibrium between infection and resistance. But it is difficult to reconcile this view with the recorded prevalence of epidemics in two successive years in Cuddapah taluk, including Cuddapah town itself where the meteorological conditions were recorded.

Rao (1929) reported that several villages in Nandyal and Sirvel taluks of Kurnool district suffered from a severe epidemic of malaria during the later months of 1928. That the high spleen rates recorded in this area in 1929 were due to a condition of post-epidemic hyper-endemicity is shown by the great diminution they had undergone when they were next examined after an interval of five years. Table III shows spleen rates in 1929 and in 1934 in some of the villages in the area recorded in either case in March-April.

* Italics are mine.—(D. K. V.).

TABLE III.

Name of village.	1929. Number of children examined.	Number with enlarged spleen.	Spleen rate, per cent.	1934. Number of children examined.	Number with enlarged spleen.	Spleen rate, per cent.
Ayalur ..	56	26	46	66	0	0
Billalapuram	30	18	60	44	3	7
Kottala ..	76	34	44	88	1	1
Owk ..	100	83	83	158	19	12
Nandyal M. T.	1,095	559	51	237	26	11

The epidemic character of the disease in 1928-29 is further borne out by the number of 'malaria' cases treated as out-patients at the Municipal Hospital, Nandyal, from 1924 to 1933 shown in Table IV.

TABLE IV.

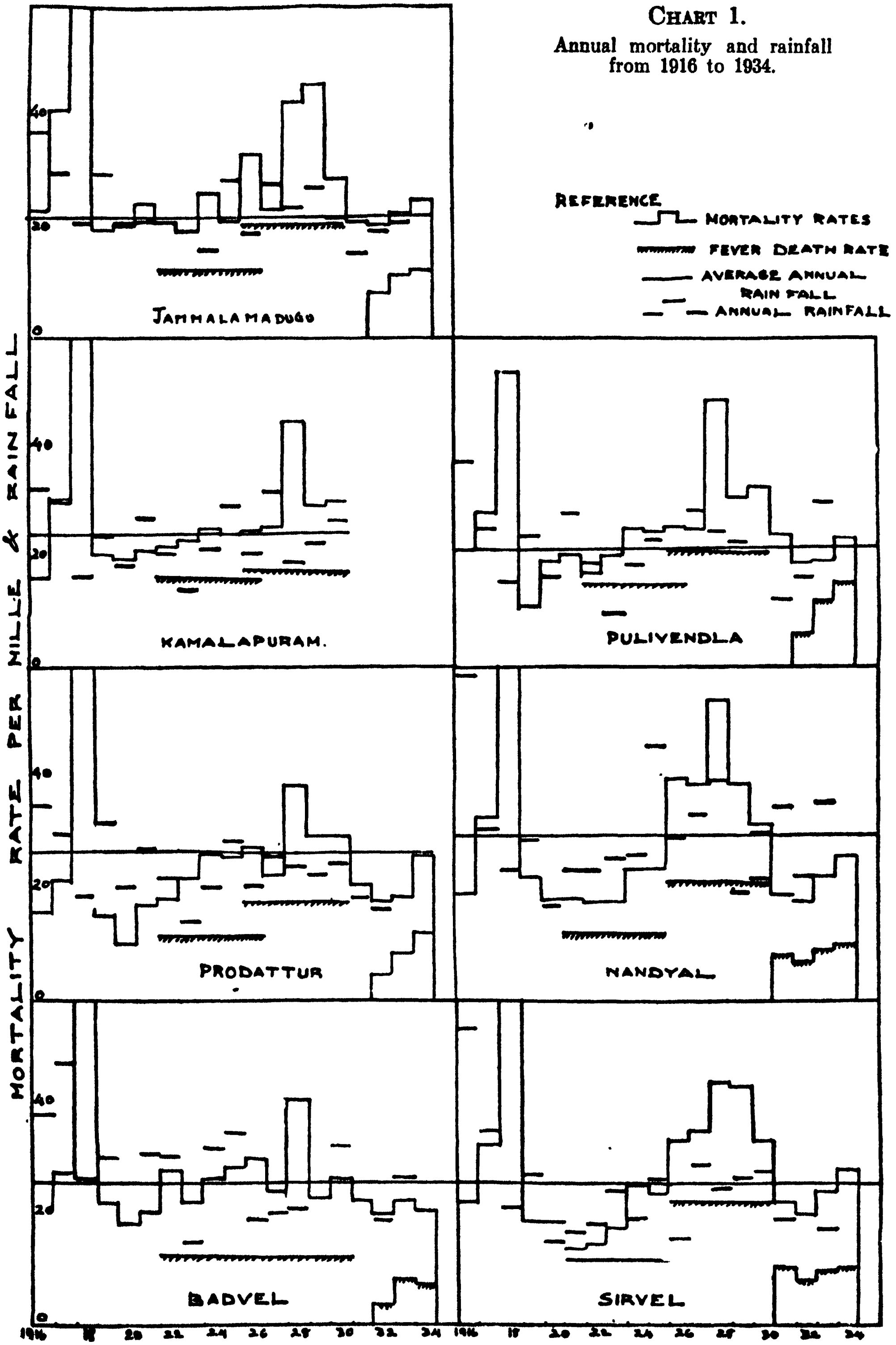
Year.	Number of malaria cases treated.
1924 ..	1,499
1925 ..	1,532
1926 ..	1,495
1927 ..	1,118
1928 ..	**3,864**
1929 ..	**4,287**
1930 ..	1,736
1931 ..	1,784
1932 ..	1,269
1933 ..	2,346

The death rate in Nandyal municipality in 1928 was 45 3 as against an average death rate of 21·6, for the previous five years, and the fever death rate was 18 8 in 1928 as against an average of 8·6 for the previous five years. Although no epidemic figures have been worked out, the severity of the disease can be judged from the fact that the total annual mortality, as well as fever mortality, was more than twice the average.

This epidemic not only involved Nandyal and Sirvel taluks of Kurnool district but also five out of nine taluks of the adjoining Cuddapah district. Although this epidemic was not studied in detail, its malarious nature has been established by the high spleen rates and the high parasite indices recorded in a few representative villages which were then visited. The enhanced mortality occasioned by this epidemic in 1928 and, in some cases in 1929 as well, will be seen in Chart 1 which shows the annual mortality from 1916 to 1934 in the seven taluks mentioned above. The annual rainfall for the above

CHART 1.

Annual mortality and rainfall from 1916 to 1934.



period is also shown in the chart. The relationship between monsoon rainfall and epidemic malaria is a matter requiring further detailed study. But in the Ceded Districts of Madras, which include Kurnool and Cuddapah, an additional difficulty may be introduced in that the rainfall recorded in the taluk head-quarter station may not be a true representation of the rainfall in the villages.

Marked and successive reduction in the spleen rates was first noticed in Kanigiri and Udayagiri taluks in Nellore district. King and Krishnan (1929) reported the occurrence of malaria in the Mopad Irrigation Project area in these two taluks and recorded a spleen rate of over 50 per cent. The dam built across the Manneru river in connection with this irrigation project was found to have raised the level of subsoil water lower down and caused a large number of pools in the bed of the river below the dam. These pools were found to breed *A. culicifacies* in large numbers. The prohibition of wet-crop cultivation, or an efficient method of drainage to prevent water-logging below the dam, were the alternative suggestions put forward as a result of this survey.

Although it was realised that the disease had occurred in epidemic form just before the survey and mention was made in the report that the older residents of Udayagiri reported that a similar epidemic had occurred about 10 years previously, these recommendations were made, because active transmission of malaria by *A. culicifacies* was still found to be taking place in November 1926.

Rao (1929), after another survey of the area, recommended the removal of 'Jambu' grass which was found to afford shelter to *A. culicifacies* breeding in pools in the river below the dam, or, as an alternative, to encourage the villagers on the banks of the river to move to a more distant and elevated site. With regard to Udayagiri, he recommended the employment of a Malaria Inspector and a gang of coolies to do anti-larval work. Jambu grass was accordingly removed from a certain portion of the river, but this work was later given up on account of financial stringency. The Malaria Inspector and a gang of coolies were employed from 1930 to 1932 but their work consisted mainly of removal of prickly pear and in canalising the streams in Udayagiri. Practically no larvicide was used. In 1932, when the writer visited the area in connection with an inspection on the working of the scheme of free distribution of quinine which had been in force in these two taluks since 1928, it was found that the spleen rate in Udayagiri was only 12 per cent as compared with the spleen rate of over 50 per cent recorded in 1926 by King and Krishnan (1929) and later by King and Ramaswami Ayyar (1929). Such a marked reduction of the spleen rate in the absence of any effective anti-larval work was surprising. However the examination of the spleen rates in the surrounding areas in the taluk and in the Mopad Irrigation Project area showed that this reduction was shared by all the villages. The spleen rates in most of these other villages, which previously recorded a spleen rate varying from 30 to 60 per cent, were now nil. This marked reduction in the spleen rates cannot altogether be attributed to the system of free distribution of quinine in force since, for one thing, comparatively few children resorted to the treatment and such of them as did mostly took only partial 'treatments'. For another, there has been a steady and marked decline in the number of people resorting to treatment from 1928 onwards. In addition, intensive quininisation, which has been in progress in the submontane endemic tracts of South Kanara district for the last six or seven years, has not been observed to bring about any material reduction

in the spleen rate, although it seems to have had an appreciable effect in the reduction of total mortality. There is therefore no doubt that the high spleen rates recorded in Kanigiri and Udayagiri taluks in 1926 were due to conditions of post-epidemic hyper-endemicity. Table V shows the comparative spleen rates in some typical villages in this area.

TABLE V.

Name of village.	1926. Number of children examined.	1926. Number with enlarged spleen.	1926. Spleen rate, per cent.	1933. Number of children examined.	1933. Number with enlarged spleen.	1933. Spleen rate, per cent.
Udayagiri	150	80	53	222	26	12
Masayapet and Gangareddipalli.	40	28	70	68	2	3
Mopad	40	31	77	30	0	0
Botlagudur ..	35	26	74	51	5	10
Inimerla	25	9	36	40	0	0

As the epidemic was more or less restricted to a few villages in Kanigiri and Udayagiri taluks, it made no striking difference in the total annual mortality rates in either of these taluks as a whole during that year. But the mortality rates in the individual villages affected were very high.

Rao (1931) reported the occurrence of a severe epidemic of malaria in several taluks in Chittoor district. 'The present widespread outbreak of malaria had its beginnings in September last year and the situation became very much aggravated during the cold weather months of November and December and again during the spring months of 1931'. 'Such a wave seems

TABLE VI.

Year.	Rainfall in inches.
1921 ..	32·75
1922 ..	38·17
1923 ..	22·80
1924 ..	32·05
1925 ..	36·46
1926 ..	33·44
1927 ..	26·07
1928 ..	31·84
1929 ..	31·39
1930 ..	52·15

to have passed over not only Chittoor district but also parts of Anantapur and the contiguous areas in Mysore state'. 'The fall of rain was remarkably heavy during 1930' compared with the figures for previous years as shown in Table VI.

Table VII shows the number of 'malaria' cases treated in some of the dispensaries in Chittoor district.

TABLE VII.

Year.	Punganur.	Piler.	Sadam.
1926	539	654	2,291
1927	377	650	1,912
1928	319	901	3,133
1929	288	2,913	3,688
1930	1,164	4,875	6,493

Table VIII shows the comparative spleen rates in some representative villages.

TABLE VIII.

Name of village.	AUGUST, 1931			AUGUST, 1932.		
	Number of children examined	Number with enlarged spleen.	Spleen rate, per cent.	Number of children examined.	Number with enlarged spleen.	Spleen rate, per cent.
Angallu	36	20	55	43	14	33
Kurubalakota ..	122	71	59	57	13	23
Kottavuru ..	34	29	85	51	25	49
Peddatippasamudram ..	233	156	67	95	27	29
Kandukuru ..	77	54	70	68	28	41
Maddayyagaripalli ..	37	25	69	29	9	31
Chinnatippasamudram	109	43	39	92	13	14
Kalrodpalli ..	69	39	56 *	28	19	68 *
Panapakkam ..	33	4	12	69	9	13

* Probable endemic focus in Chandragiri taluk.

A few localised epidemic outbreaks of malaria have also been reported by Rao (1931) along the coastal villages in Vizagapatam and Ganjam districts in 1930. The epidemic in 1928-29 in Ganjam, though it was localised, was associated with a very high mortality to which reference has been made by the Public Health Commissioner with the Government of India in his annual report for the year 1930, quoted by Sinton (1935).

SUMMARY.

1. The Ceded Districts of Bellary, Anantapur, Kurnool, Cuddapah and the contiguous areas in Chittoor and Nellore districts and coastal belts in Ganjam and Vizagapatam districts, are liable to epidemic outbreaks of malaria attended with a high total annual mortality (ranging, for instance, from 39 per mille in Proddatur to 49 per mille in Nandyal taluk in the 1928 epidemic).

2. These epidemics are associated with a marked increase in rainfall.

III. THE EPIDEMIC OF 1933-34 IN MADAKASIRA TALUK IN ANANTAPUR DISTRICT AND IN HARPANAHALLI, HADAGALLI AND KUDLIGI TALUKS IN BELLARY DISTRICT.

1. INTRODUCTORY.

Madakasira was surveyed in March 1930 by Rao (1930) in his general malaria survey of Anantapur district. The writer has since visited the area twice, first in September 1933 in connection with the examination of the free distribution of quinine in the district and again in April 1934 when the mortality due to the epidemic was at its height. In the first survey which was made by Rao in 1930, only the headquarters of the taluk, Madakasira, was included in a spleen and parasite survey. In a second survey made by the writer in September 1933, seven out of the fifty-four villages in the taluk reported to be involved in an epidemic—including the headquarter town—were visited. A third survey included four villages in addition to the headquarter town. It was only in April 1934 that a detailed mosquito survey was done. In September 1933, however, a number of larval specimens were collected in the course of a rapid tour and later identified on reaching Madras.

Harpanahalli and Kudligi were visited only once, *viz.*, in March 1935, more than a year after the epidemic subsided. Only spleen and parasite surveys were then made. But it was this visit which revealed the magnitude of the epidemic, and which led to the compilation and study of statistics for the whole area involved in the epidemic. The material for this and the succeeding sections of this paper is based on the above investigations.

2. PHYSICAL CHARACTERS OF THE AREA.

Madakasira taluk is fairly typical of all the four taluks under reference. It is situated in the southern portion of Anantapur district and is contiguous with the Mysore plateau. This taluk (like the adjoining taluk of Hindupur) is slightly more favoured by nature than the rest of the district, lying at a higher elevation, and having a heavier rainfall (24 25 inches as against 22 to 23 inches for the district as a whole). Its vegetation is thicker, soil more fertile and the irrigated area more extensive. It is less sparsely peopled and maintains a higher rate of increase in its population. It has been rather extravagantly called the 'garden of the district'.

3. METEOROLOGY.

(*a*) Rainfall.

The rainfall is distributed in the different seasons of the year as shown in Table IX.

TABLE IX.
(*In inches.*)
Average figures for 60 years, 1870—1930.

	January to March.	April and May.	June to September.	October to December.	Total.
Madakasira ..	0·49	3·96	11·75	7·30	23·50
Harpanahalli ..	0·29	3·54	13·98	5·95	23·76
Hadagalli ..	0·41	3·31	12·87	5·47	22·06
Kudligi ..	0·23	3·17	15·48	5·66	24·54

The wettest months are September and October, during which is registered nearly half the total annual rainfall. The rain is not only scanty but usually falls in light showers, which on a stony soil under a tropical sun, soon dry up and are insufficient to fill the tanks and wells. Further it is most capricious and uncertain.

(*b*) Temperature.

The three hottest months are March, April and May, during which the average maximum temperature remains between 100°F. and 104°F. and the average minimum from 72°F. to 78°F. In June, the average maximum temperature drops suddenly 8 or 10 degrees, and thereafter gets lower month by month till December, when it registers about 86°F. The average minimum temperature drops more gradually to about 61°F. The nights and early mornings from November to January are delightful, the thermometer frequently falling below 55°F.

(*c*) Humidity.

There are no records of humidity, but the two districts are the driest in the Presidency.

4. PREVIOUS RECORDS OF ILL HEALTH.

The *Gazetteer* refers to Anantapur as 'quite a healthy district in the Presidency being free from the malaria which infests so much of the other three Deccan districts' (Bellary, Kurnool and Cuddapah).

The first survey, which Rao (1930) carried out in March 1930, however, showed that there were a few endemic foci of the disease in the eastern and northern portions of the district. The western and southern portions were comparatively free.

In Madakasira, the spleen rate was only 1 per cent in 1930 (four out of 316 children alone showing enlarged spleen). The parasite index was nil.

Rao (1931*a*) carried out another survey in Anantapur district on account of the reported occurrence of an epidemic in the western taluks, namely Kalyandrug and Penukonda. Madakasira taluk was not then visited, because no reports were received of any undue prevalence of the disease in that taluk. The Madakasira dispensary figures, however (*vide* Chart 2), show that in this taluk there was a perceptible increase in the incidence of the disease with three distinct waves of morbidity, the first in April, the second in July-August, and the third in November 1931.

Kudligi taluk in Bellary district is described in the *Gazetteer* as liable to malaria prevalence though less so than in previous years—indicating its liability to epidemic incidence. Harpanahalli and Hadagalli are usually known to be free from malarial endemicity. In certain other taluks in the district like Hospet and Siruguppa, malaria is endemic in the Tungabhadra riverside villages and in the villages situated on the banks of irrigation channels arising from this river.

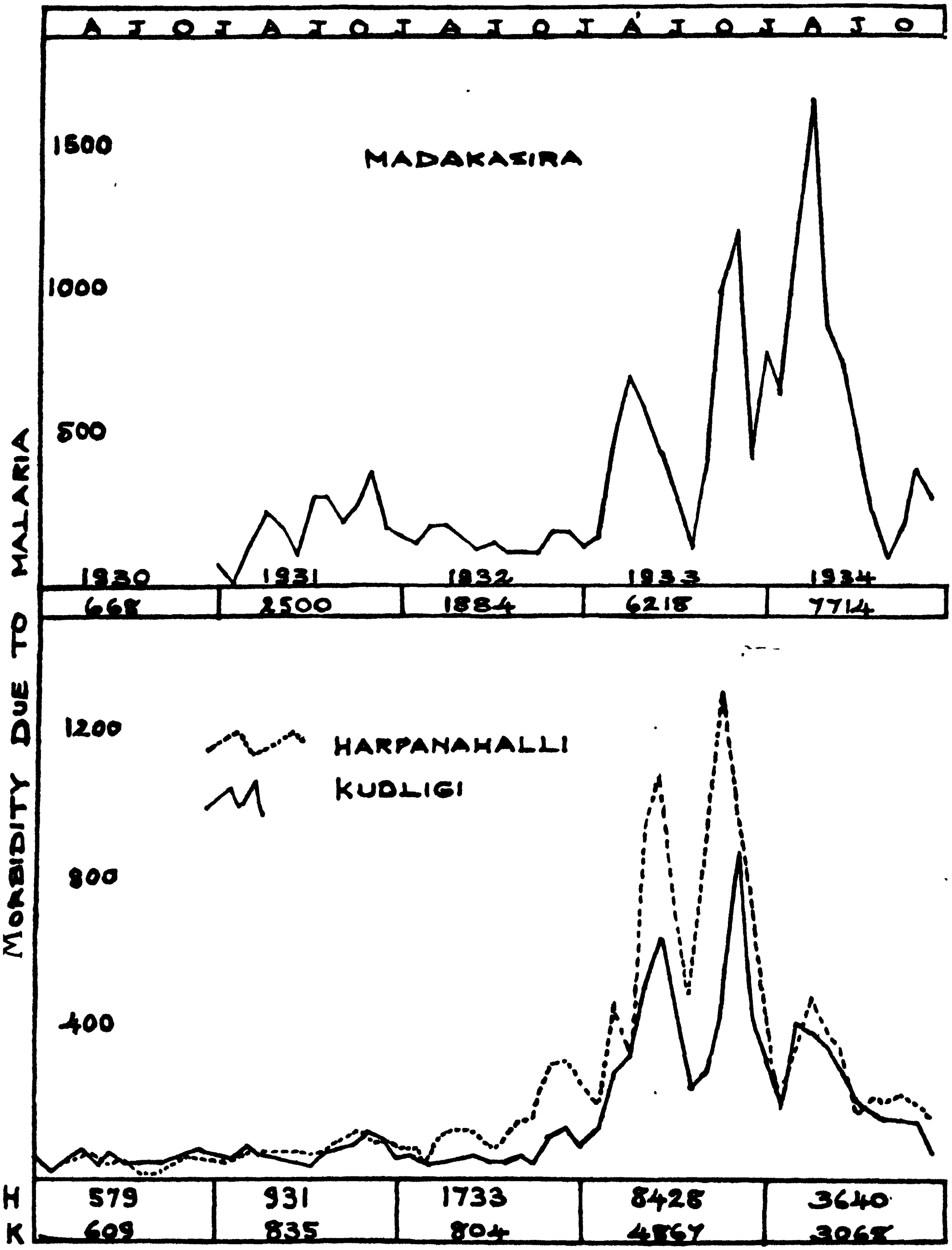
5. HISTORY OF THE PRESENT EPIDEMIC.

(*a*) Morbidity.

Chart 2 shows the number of 'malaria' cases treated in the dispensaries at Madakasira, Harpanahalli and Kudligi.

CHART 2.

Dispensary malaria cases.



References.

A — April. J — July. O — October.

Madakasira.—The year 1932 was comparatively healthy from the point of view of malaria, although one could detect a slight rise in the incidence of 'malaria' in March-April and again in December 1932.

The first sharp rise in morbidity, marking the commencement of the great epidemic which was to follow, occurred in March 1933, and the first peak was reached in April. There was then a fairly rapid subsidence in May, June and July, and the morbidity reached the pre-epidemic level in August. There was then a second and greater wave of incidence in September and October, and the second and higher peak was reached in November 1933. There was a rapid fall in December 1933, although the morbidity in that month remained very much higher than the pre-epidemic level. The third and even greater wave of 'malaria' morbidity commenced in January 1934, and the third and highest peak was reached in April 1934. The apparent slight decrease in February 1934 is probably due to the smaller number of days in this month. The incidence fell rapidly in May, June, July and August, and reached the pre-epidemic level of incidence in September 1934. There was another small wave in November 1934.

The present epidemic had thus three well-marked progressive waves of increased incidence of 'malaria'—the first peak in April 1933, the second in November 1933 and the third in April 1934. On account of this epidemic, the customary rise in the incidence of malaria towards the end of the year was accentuated in November 1934.

Harpanahalli.—In April, May and June 1932 the incidence of malaria was slightly greater than in the two previous years. This enhanced prevalence was continued in July, August, September and October, and there was a further sharp rise in November and December 1932. There was then a slight decrease in January and February 1933, followed by another wave of yet higher incidence in March 1933. This was followed by a slight fall in April, but in May there was again another sharp rise and the first great peak of incidence was reached in June, followed by a fall in July and August. In September 1933 the incidence again rose sharply and in October 1933 the highest peak of incidence was reached. The incidence fell rapidly in November and December 1933 and during January and February 1934. The drop was followed, however, by a small further rise in March and April. During the next four months there was a steady fall, and, from July 1934 onwards, the incidence remained stationary at a level slightly higher than in the pre-epidemic period.

Kudligi also presents similar features, except that the peaks are not so high as in Harpanahalli. The population of Kudligi, however, is only 4,117 whereas the population of Harpanahalli is 8,773.

The morbidity curves of the three taluks mentioned present the common feature of multiple waves occurring at intervals of a few months. There are a number of progressively increasing waves before the highest peak of incidence is reached, but there is only one secondary wave of small proportion after it.

(*b*) Relation of morbidity to rainfall.

Madakasira.—Chart 3 shows that there was 32 inches rain in 1932 and 34 inches in 1933 as compared with an average rainfall of 24 inches per annum in the taluk. Two consecutive years of such heavy rains had not occurred in the taluk during the last 30 years.

From the point of view of malarial incidence of much greater significance is its distribution during the year. The monthly rainfall in inches during the years 1932, 1933 and 1934 is shown in Chart 4. The increase in rain in 1932 occurred mainly in the months of October (more than 12 inches as against an average of 5 inches) and November (more than 3 inches as against an average of 2 inches). In a district which is usually very dry, this large increase in the rains filled up all the tanks and raised the level of subsoil water in the villages to within a foot of the ground level, because the villages are mostly situated at the foot of a slope and the tanks at its head.

CHART 3.

Reference same as in Chart 1.

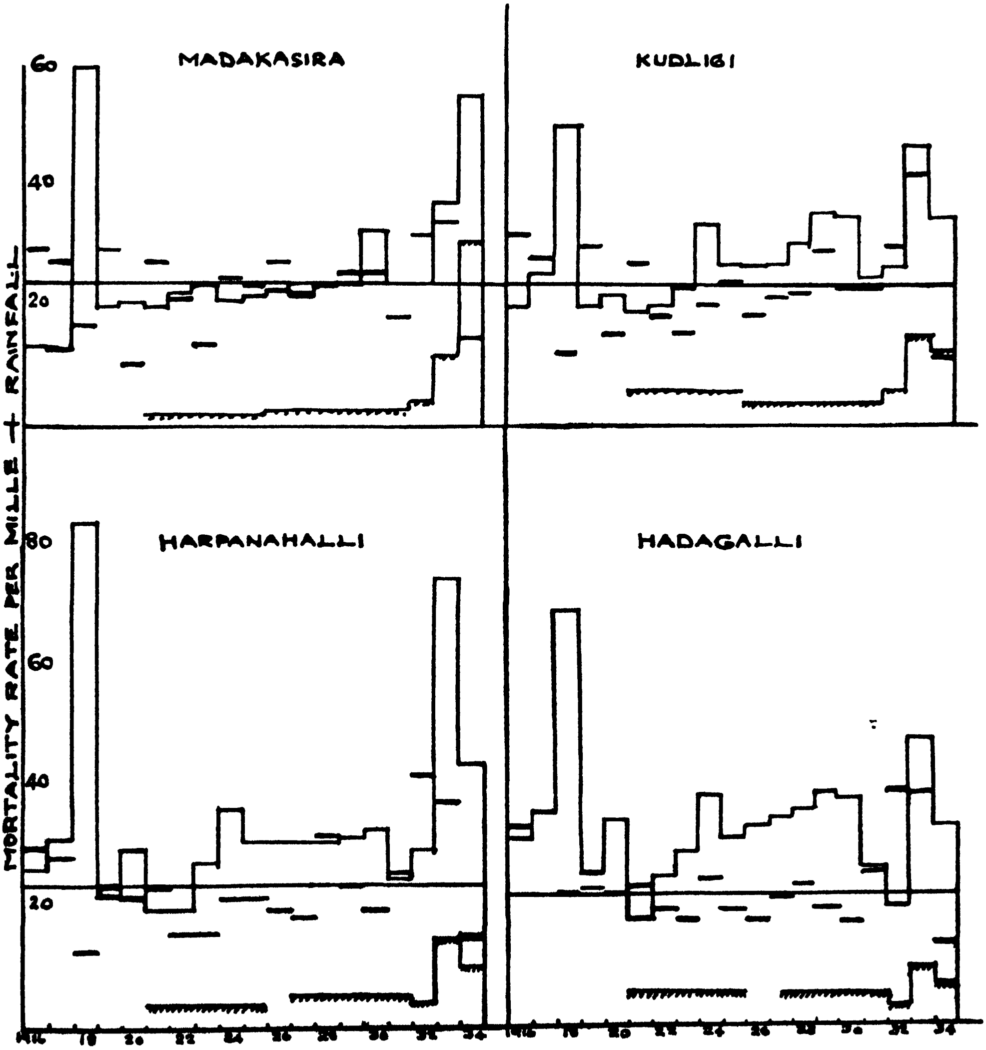
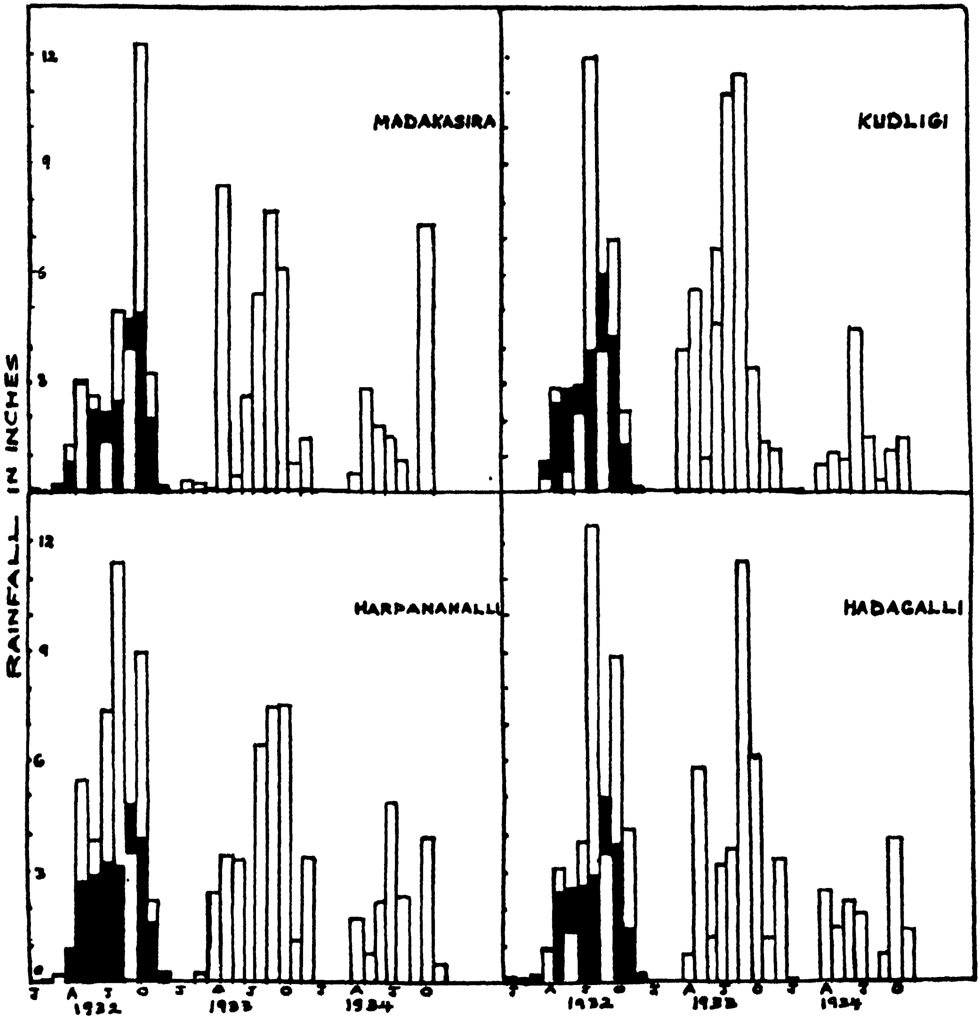


CHART 4.
Showing monthly rainfall from 1932 to 1934.
Shaded figures denote monthly average rainfall.



It will be seen that there is a lag of about four months between increased rain in October and November 1932 and the first great rise in the incidence of the disease in March-April 1933. There was over 8 inches of rain in May 1933, against an average of about 3 inches. But there was a defect in rain in the month of June, and in July only the normal incidence of rain occurred. August, September and October, however, experienced 19 inches of rain as against an average of 12 inches. Thus the tanks and other hollows in the vicinity of the villages, which usually dry up in the intense heat of the summer, remained full from November 1932 to the end of the year 1933, and therefore not only facilitated the breeding of mosquitoes, but also tended to raise the humidity and thus

provided continued facilities for the transmission of the disease throughout the year. There was no rain in the first quarter of 1934, and yet in this period occurred the third and highest peak of the incidence of the disease (March 1934) which is, therefore, due to the effects of the rainfall which occurred three months earlier. In this part of the province, therefore, there appears to be a lag of at least three months between the occurrence of the rainfall increased well above the average and a marked increase in the incidence of the disease.

Harpanahalli.—As in Madakasira, there was marked increase in rainfall in 1932 (42 inches) and in 1933 (38 inches) as against an annual average of 24 inches. But, while the increase in rainfall in 1932 occurred mainly in October and November, in Madakasira, it occurred in Harpanahalli during every month from May to November, except in the month of September. The highest rainfall was recorded in the month of August 1932 (nearly 12 inches as against an average of 3 inches), and the first sharp rise in the incidence of malaria is seen in the month of November, *i.e.*, three months after the highest incidence of rain. The next month, in which there is a great increase in the incidence of rain, was October 1932 (9 inches as against an average of 4 inches) and the next sharp rise in 'malaria' incidence was in March 1933. In April 1933, there was nearly 3 inches of rain as against an average of an inch. Although 3 inches of rainfall may not have any appreciable effect by itself in the Ceded Districts, the increased incidence of rain following upon a year of heavy rainfall was apparently responsible for a further sharp rise in malarial incidence in May and June 1933. July, August and September 1933 registered a total rainfall of 21 inches distributed fairly evenly as against the average of 9 inches. This was followed by a second and higher peak of the incidence of the disease in October 1933. In 1934, the rainfall was very much in defect. The small rise in the incidence of the disease in April 1934 is probably a post-epidemic secondary rise.

Kudligi.—The first sharp rise in the incidence of rain was in August 1932 (12 inches as against an average of 4 inches), and the rainfall in the previous months was slightly in defect of the average. This was followed by a slight increase in the disease in November and December, *i.e.*, about four months later. In October 1932, the rainfall was 7 inches against an average of 4 inches, and in November it was about 2 inches as against an average of 1 inch. This was followed by a sharp rise in malarial incidence in March 1933. In April and May 1933 there was 9 inches of rain as against an average of 4 inches, and the first high peak in the incidence of the disease was reached in June 1933. In July, there was about 4½ inches of rain as against an average of less than 3 inches, but in August and September there was 22 inches of rain against an average of 9 inches and the second and highest peak of the incidence of the disease was reached in November 1933, *i.e.*, more than two months later. As in the other two taluks, the rainfall in 1934 was very much in defect in Kudligi also.

Considering the data from all the three taluks together, a marked increase in the occurrence of rain is followed after an interval of about 3 months by a distinct rise in the incidence of malaria. When, however, increased rainfall in one year is followed by a further marked increase in rainfall in the next, multiple waves of malaria incidence occur at intervals, with a progressive increase in their amplitude.

(*c*) Spleen rates.

Table X shows the spleen rate in Madakasira, Harpanahalli and Kudligi at the different periods when such examinations were made.

Table X.

When examined.	Number of children examined for spleen.	Number with enlarged spleen.	Spleen rate, per cent.
	Madakasira.		
March 1930 ..	316	4	1
September 1933	218	30	14
April 1934 ..	119	83	70
	Harpanahalli.		
March 1935 .	369	63	17
	Kudligi.		
March 1935 ..	107	57	53

In Kudligi and Harpanahalli, the spleen census was made a year after the epidemic subsided. As the amplitude of the highest peak of the mortality rate in Harpanahalli was much greater, one would have expected a higher spleen rate in this taluk. But both from the report in the *District Gazetteer* and from local information, Kudligi is apparently liable to a certain degree of endemic malaria from year to year, whereas Harpanahalli is supposed to be much healthier.

(*d*) Parasite findings.

Madakasira.—In March 1930 no parasites were found in 30 smears examined. In September 1933, the parasite index was 15 per cent (15 out of 100 smears showing malaria parasites). Of these, seven (47 per cent) were *P. vivax*, five (33 per cent) *P. falciparum* and three (20 per cent) *P. malariae*. The average parasite prevalence, determined by Sinton's method, was 250 per c.mm. Four out of the 15 positive smears (out of 100 total smears examined) showed gametocytes. In April 1934, the parasite index was 45 per cent (64 out of 143 smears being infected). The relative prevalence of the species was as follows: *P. vivax* (51 per cent); *P. falciparum* (41 per cent); *P. malariae* (nil); mixed infection (8 per cent). Seventy-six adults were also examined in April 1934 and among them 56 or 74 per cent showed malaria parasites. But quite a large number of them were actual fever cases who came up to my camping place for purposes of examination and in expectation of treatment. The relative prevalence of the species among the adults was 43 per cent *P. vivax*, 32 per cent *P. falciparum*, and 25 per cent mixed infections. The average parasite prevalence was 800 per c.mm. amongst children and 1,200 per c.mm. among adults, in April 1934. The increased parasite prevalence in adults is due probably to a much greater number of actual fever cases being

included in the examination; or again it may be that the children included in the April examination were only those who had survived the effects of the epidemic, for quite a large number who had heavy infections had already fallen victims to the disease owing to their feebler powers of resistance.

Although blood examinations were not made from month to month during the course of the epidemic, both in September 1933 and April 1934, the relative prevalence of *P. vivax* and *P. falciparum* appears to be the same. It is quite possible that if blood examinations had been carried out in November and December, or early in March 1934, when the greatest mortality was occasioned by the disease, a higher proportion of *P. falciparum* infections might have been found. The present findings, however, show that *P. falciparum* infections persist in quite large numbers as late as April, notwithstanding its reputed tendency to be more prevalent in the autumn.

Harpanahalli and Kudligi.—Table XI shows the parasite findings in these two stations. These examinations however were made in March 1935, long after the epidemic was over.

TABLE XI.

	Number of smears examined.	Number infected.	Parasite index, per cent.	Species.
Harpanahalli ..	17	1	6	B. T. trophozoites.
Kudligi ..	30	7	23	4 B. T. rings and trophozoites. 1 B. T. and M. T. rings. 1 M. T. rings. 1 M. T. crescents.

(c) MOSQUITO FINDINGS.

Madakasira.—The principal breeding grounds in this taluk consist of irrigation channels flowing in easy gradients from the tanks to the cultivable lands in the villages; irrigation fields; pits and depressions in and about the village site, and wells. In 1933, the level of subsoil water was so high that for the first time in 30 years people resorted to wet cultivation. Indeed they had no option in the matter, because of the water-logged condition of the soil. No detailed mosquito survey was done in September 1933, since the main object of the tour at the time was to supervise rapidly the free distribution of quinine. Specimens of larvæ collected from a few irrigation channels and a few wells were later identified as *A. culicifacies*, *A. subpictus* and *A. stephensi.*

In April 1934 the larval findings were very meagre. There had been no rain in the first three months of the year, and on account of intense heat in the summer, all the breeding grounds were drying up rapidly. But on a search for adult anophelines in the houses, 93 anophelines were collected on four consecutive days, and were dissected. The results are shown in Table XII.

All the adult mosquitoes showed ovaries in fourth stage of development. Obviously conditions for mosquito life were getting very unfavourable. Considering that *A. culicifacies* was the only species found infected, and considering

TABLE XII.

Species.	Number collected and dissected.	Number found infected.		Total infection, per cent.
		Oöcysts.	Sporozoites.	
A. culicifacies	70	2	2	6
A. stephensi	4	—	—	—
A. hyrcanus	6	—	—	—
A. annularis (*A. fuliginosus*)	4	—	—	—
A. subpictus	9	—	—	—

its large relative numerical prevalence, it is probable that the species was the main, if not, the only vector during the last epidemic.

(*f*) Effects on mortality.

(*i*) *Cyclical periodicity.*

In Chart 3 are given the annual total mortality rates for the period 1916 to 1934 in the four taluks of Madakasira, Harpanahalli, Kudligi and Hadagalli, together with the annual rainfall in inches. The chart shows two high peaks of mortality, one in 1918 due to the great influenza pandemic, and the other in 1933 in the three western taluks of Bellary district and in 1934 in Madakasira taluk in Anantapur district. In Madakasira, the epidemic also occasioned a high mortality in 1933 but, as this was confined to the period November-December, the total annual mortality in that year was not so great as in the western taluks of Bellary. There was, however, a considerably enhanced mortality in March 1934, which is reflected in the marked increase in the annual mortality rate for that year.

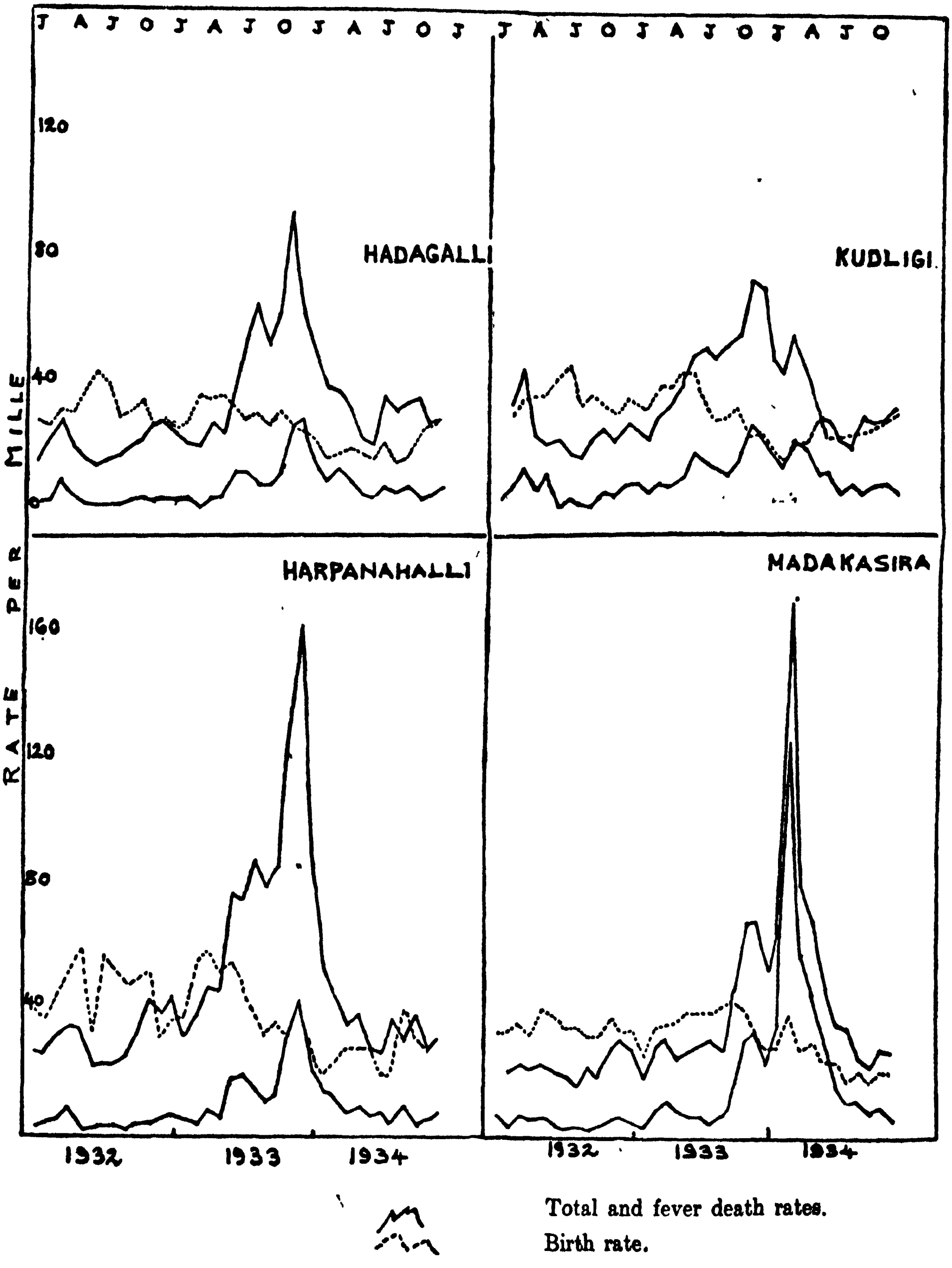
Studies of annual total mortality rates have obvious limitations in assessing the periodicity of epidemics. Although in common with statistics from other parts of the country, such rates are more reliable than the 'fever' mortality rates, because of the inclusion of a large number of deaths due to undetermined causes under the heading 'fevers', epidemics of moderate intensity confined to a few months, may not alter the total annual mortality rates to any striking degree. To assess the cyclical periodicity, therefore, monthly epidemic figures have to be worked out or for any other convenient unit of time during a series of years. This work has, however, been deferred for further study. From Chart 3 it will be found that in 1924 the annual total mortality rate shows a distinct rise in Harpanahalli, Hadagalli and Kudligi and in 1930 in Madakasira. The significance of this increased mortality has also been left over, for later study.

(*ii*) *Seasonal incidence.*

Chart 5 shows the monthly birth, death and the fever death rates, during the period 1932 to 1934 in all the four taluks. The course of the epidemic, judging from its effects on the mortality, was as follows in the four taluks. The normal monthly mortality rate is fairly well represented by the year 1932, and the increase in mortality in November, December and January, a feature common

CHART 5.

Showing birth, death and fever death rates.



to the province as a whole. In the endemic areas it is not uncommon to have an increased mortality in March-April also.

Madakasira.—The mortality began to rise considerably in October 1933; the first peak was reached in November and maintained in December. There was then a slight decline in January 1934, but February is marked by a further ascent in the mortality rate which however rose rapidly to 175 per mille in the month of March. April is marked by an equally rapid descent which was maintained in the next few months until the pre-epidemic mortality level was reached.

Harpanahalli.—The first great rise in mortality occurred in June 1933, and the first peak was reached in June-July. The August rise is due in part to the occurrence of plague, and, if deaths from plague are excluded, there will be a distinct fall in August. There is then a second rise in September and October, and the next and bigger peak of mortality is reached in December 1933. A rapid fall occurred in January and slightly less rapid fall in February and March. The fever mortality rate runs very nearly parallel with the total mortality rate.

In Kudligi and Hadagalli, the trend of the epidemic in its effects on mortality is very nearly the same as in Harpanahalli.

From the foregoing, it will be seen that the intensity of the epidemic was very great, occasioning, as it had done, at its height, a mortality rate ranging from 175 per mille in Madakasira taluk, 164 in Harpanahalli taluk to 96 per mille in Hadagalli taluk and 70 per mille in Kudligi taluk. In the three western taluks of Bellary district, the height of the mortality was reached in November-December 1933, but in Madakasira taluk it was recorded in March 1934. Gill (1928) states that he has been able to discover in the literature on malaria no instance of the occurrence of widespread epidemics possessing 'regional' characters save in the autumn. Whether the Madakasira epidemic can deservedly be called a 'regional' epidemic or not, it has certainly affected a whole taluk comprising 446 square miles in extent with a population of 97,081 (as reported in the 1931 census) and occasioned as great a mortality in the month of April as the regional epidemics of the Punjab in autumn.

(*iii*) *Wave form.*

The characteristics of the regional epidemics of the Punjab with regard to the wave form are summarised by Gill as—

(1) having a strictly autumnal periodicity;

(2) commencing with abruptness in the second or third week of September, reaching its maximum in October, and declining gradually in the months of November and December. In January the mortality is once more normal and no subsidiary or secondary waves of mortality subsequently occur. Sometimes the emergence of the epidemic is accelerated, when it reaches its maximum intensity in September, or retarded when it reaches it in November;

(3) the wave sometimes exhibits a notch near its peak but it is single;

(4) the rise in the curve is somewhat more abrupt than the fall and hence the curve is asymmetrical.

The epidemic now under reference did not have a strictly autumnal periodicity.

CHART 6.
Mortality in age groups.

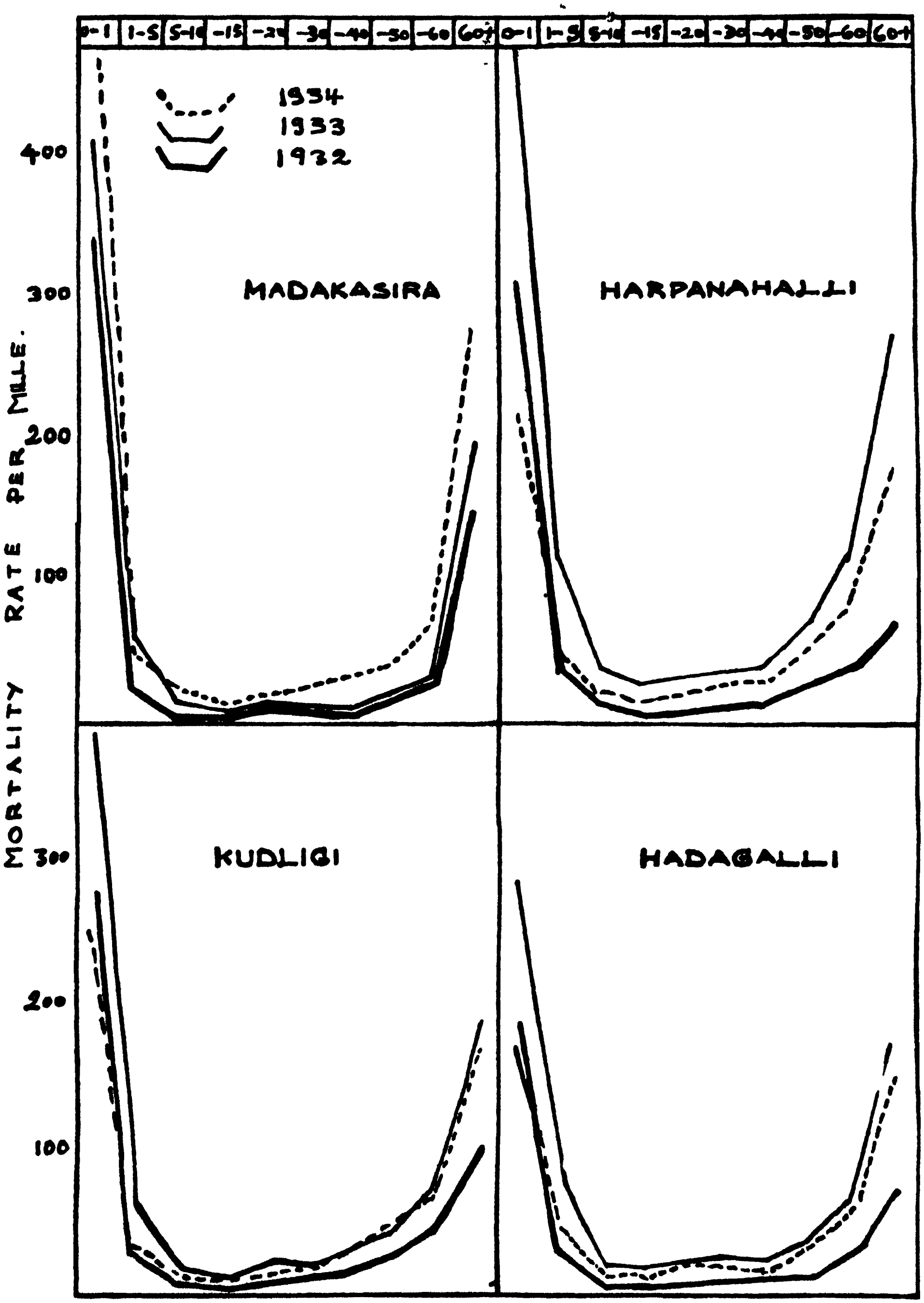
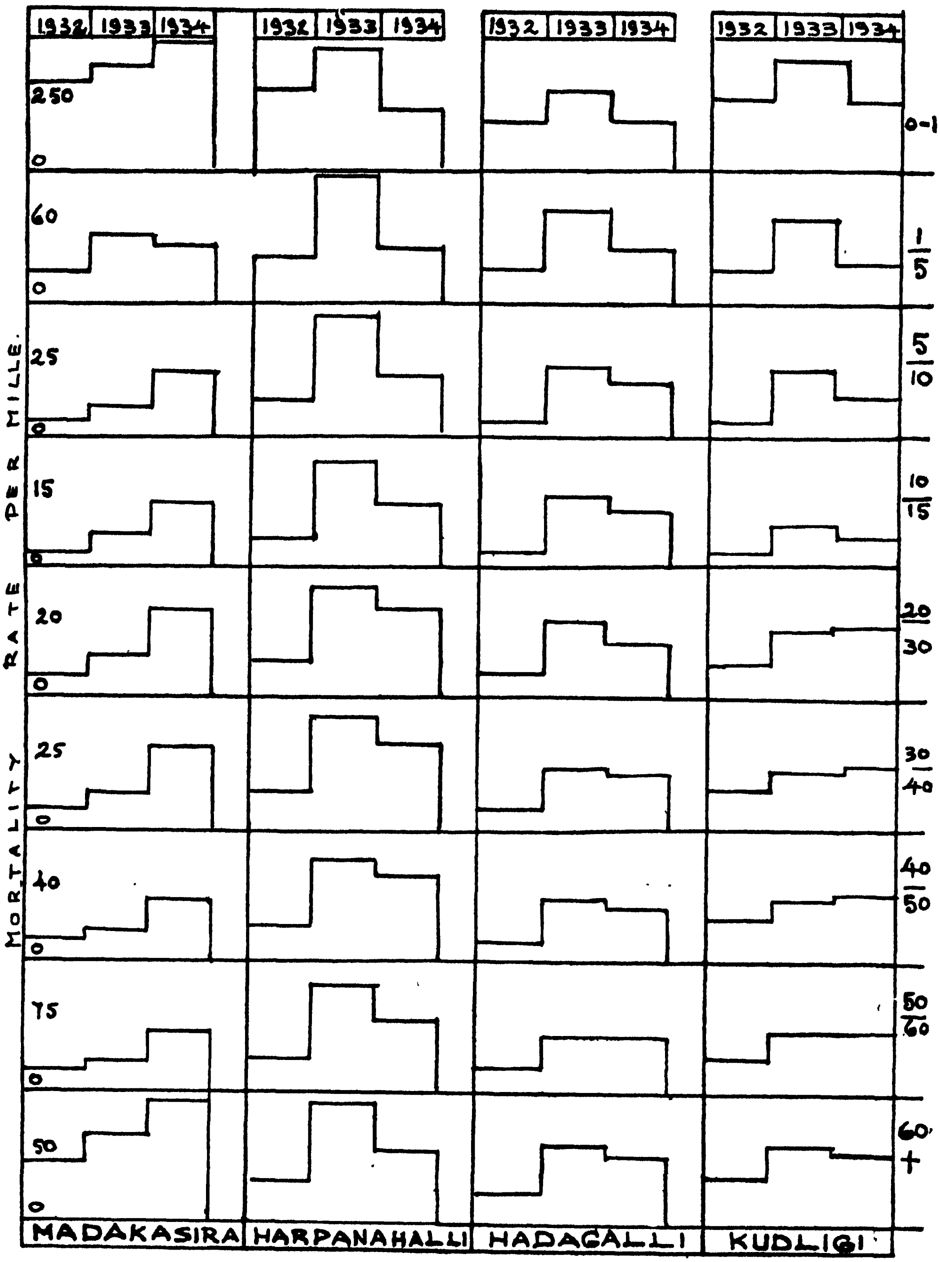


CHART 7.


1932
1933
1934
MORTALITY RATE PER MILLE.
250
60
25
15
20
25
40
75
50
0
0-1
1/5
5/10
10/15
20/30
30/40
40/50
50/60
60+
MADAKASIRA
HARPANAHALLI
HADAGALLI
KUDLIGI

The base of enhanced mortality is very much more prolonged, involving a period of over six months. The mortality peak exhibits bimodal characteristics. Although the curve is asymmetrical, the rise is gradual in the beginning, but more abrupt just before the peak is reached (except in Kudligi) and the descent is first abrupt and then more gradual.

(*iv*) *Specific age incidence.*

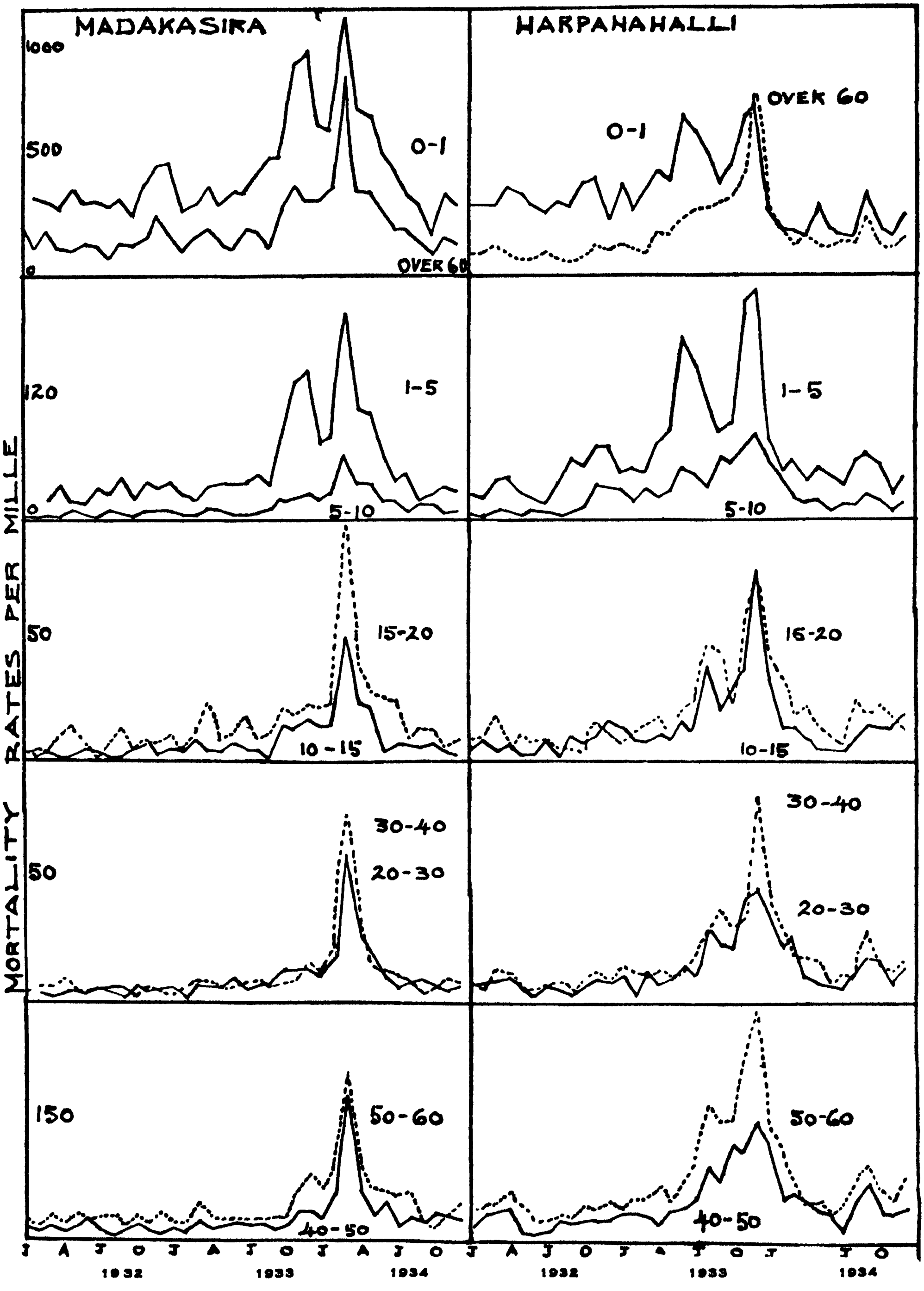
Charts 6 and 7 show the mortality in age groups in the three years—1932, 1933 and 1934—in all the four taluks. In Madakasira taluk, there is a progressive enhanced mortality in every age group (except the group 1 to 5), in the years 1933 and 1934 since the epidemic involved the later months of 1933 and the first quarter of 1934. In 1933, the relative increase is greatest in the age group 1 to 5, and gradually less marked in each succeeding age group. The absolute increase is greatest in the age group 0 to 1; while this may be due to the great susceptibility of infants under one year to any kind of infection, it must also be remembered that, the usual death rate being as high as 250 in this age group, its capacity for relative increase is proportionately more limited than the other age groups. The relative mortality in 1934 is progressively greater in each age group after 5 to 10, and the maximum relative increase is in the age group 40 to 50. In the age group 1 to 5, however, there is a relative decrease in mortality in 1934 as compared with 1933, presumably on account of the fact that the maximum relative increase had already occurred in 1933 and the population at risk in 1934 was therefore proportionately smaller. The progressive and smaller relative increase in the age group 0 to 1 in 1933 and 1934, coupled with the greatest relative increase in the age group 1 to 5 in 1933 and a relative decrease in the same age group in 1934, lends support to the well recognised feature that mortality occasioned by epidemic malaria affects children in the age group 1 to 5 more markedly in the earlier stages of its development. In Harpanahalli and Hadagalli taluks, the enhanced mortality in the year 1933 has affected every age group. The greatest relative increase occurs in the age group 10 to 15, although the other age groups, excepting 0 to 1, also show a relative increase of very nearly the same degree. In Kudligi also the same features are noticeable, but in the later age groups the increase in mortality is maintained in 1934 as well, on account presumably of the second wave of enhanced mortality in April of that year.

Even in Harpanahalli and Hadagalli taluks, the mortality is greater in the later age groups in 1934 than in 1932, thus showing that the mortality effects of the epidemic were prolonged over a long period.

Chart 8 shows the monthly mortality in age groups in Madakasira and Harpanahalli taluks during the years 1932, 1933 and 1934. The mortality curve exhibits bimodal peaks in the age groups 0 to 1 and 1 to 5, the amplitude of the first peak being only slightly less than that of the second. The amplitude of the first peak gets less and less in each succeeding age group in Madakasira until it is practically negligible in the age groups 20 to 30 and 30 to 40. It then becomes more and more pronounced in each succeeding age group. The same characteristics can also be seen in Harpanahalli, although the bimodal characteristics of the peak persist to a greater degree in age groups 15 to 20, 20 to 30 and 30 to 40 than in Madakasira.

CHART 8.

Showing mortality rates in age groups.



To summarise then, the effects of the epidemic on the specific age incidence of mortality—

1. As in the 'regional' epidemics of the Punjab, the earlier age groups up to 5 years of age are the first to be involved in the mortality occasioned by the epidemic.

2. The later age groups are then affected after a much larger interval of time than in the 'regional' epidemics of the Punjab, but unlike the latter outbreaks, there is a much greater relative increase in adult mortality.

3. On this account the mortality peak exhibits very distinct bimodal characteristics.

(*v*) *Effects on fecundity.*

The birth rate shows a progressive decline from the very commencement of the epidemic although just before the commencement of each peak there is a slight relative increase in the birth rate due presumably to the induction of premature births. The lowest birth rate was reached in Madakasira in August 1934, *i.e.*, five months after the highest peak of mortality and nine months after the first peak and this low birth rate was maintained in September, October, November and December, *i.e.*, till nine months after the second peak. In Harpanahalli, the lowest birth rate was reached in February 1934, *i.e.*, three months after the highest peak of mortality and eight months after the first high peak of mortality. The birth rate then showed a slight relative rise in the next four months, and there was again another drop in July and August 1934, that is eight to nine months after the second high peak. There was then a rise in the birth rate in September, which however was not as high as in the pre-epidemic period.

These effects are in some respects in conformity with those reported of the regional epidemics of the Punjab, such as, (*i*) an increase in the number of births at the commencement of the epidemic, (*ii*) a steady decline in the number of the births throughout the course of the epidemic till the lowest birth rate is recorded nine to ten months after the epidemic, (*iii*) a sharp rise in the births in the latter months of the year following the epidemic, and (*iv*) the establishment of the normal birth rate in the second year after the epidemic. These features are explained by Gill as follows :—On the occurrence of the epidemic a great number of premature births is induced. The steady decline in the birth rates in the next few months is due to induced abortions and miscarriages at the height of the epidemic, and not to any appreciable increase in the mortality of the adult females of child-bearing age. The lowest birth rate recorded nine to ten months after the epidemic is due to the universal sickness occasioned by the epidemic, and consequent limitations in sexual union when the epidemic was at its height. The later rise in the number of births is due to the increase in the number of non-pregnant women of child-bearing age, on account of the abnormal frequency of abortions and miscarriages when the epidemic was at its height, and on account of the lack of an appreciable increase in the mortality of adult population.

But in view of the high adult mortality occasioned by the Ceded Districts epidemic, the decline in the birth rate is most marked from the very beginning of the epidemic and is maintained for a period of nine months after its height, and even later the increase in the birth rate is not absolutely but only relatively greater. Again in Harpanahalli where the epidemic started

as early as June, its effects on fecundity are noticeable even in the birth rate of the year of its occurrence, which however is much more pronounced in the next year, as Table XIII will show.

TABLE XIII.

Birth rates per mille in Harpanahalli.

1932 .	48·2
1933 .	45·3
1934 .	28·4

IV. DISCUSSION.

The main features of the epidemic described in the previous sections show that epidemic malaria in the Ceded Districts is akin to the regional epidemics of the Punjab in so far as it was brought about by excessive rainfall, and in the chief carrier of the disease being *A. culicifacies*, probably the sole vector, in both the areas. Apart from the spatial distribution and cyclic periodicity, the detailed study of which will be considered in a later article, this Madras epidemic differs from the 'regional epidemics' of the Punjab in its seasonal periodicity, in the wave form, and, to some extent, in the specific age incidence of mortality and its effects on fecundity. More especially, however, its duration was very much more prolonged. The protracted duration of the epidemic, the bimodal peak in mortality, and the prevalence of benign and malignant tertian infections in equal proportions, are features common to this as well as the recent Ceylon epidemics.

The characteristic features of this epidemic lead us to consider in general the theories hitherto formulated about the genesis of epidemics which have been based mainly on their study in the non-tropical region, and in particular whether there is an identical mechanism in tropical and non-tropical epidemics with only a variation in detail, or whether the mechanism is fundamentally different in the two cases.

In his study of the great epidemic of 1908 in the Punjab, Christophers (1911) showed that some general determining influence, *viz.*, inundations due directly to increased rainfall locally or indirectly to flooding of rivers, was responsible for the occurrences of epidemics in places hundreds of miles apart He also showed that adverse economic conditions and marked increase in the normal seasonal rise in the parasite rate played a great part in the epidemics

The quantum theory of the genesis of malaria epidemics put forward by Gill (1928) postulates that endemic and epidemic phenomena represent the distinctive objective signs of an identical parasitic invasion, which, in circumstances associated with constancy of infection, gives rise to the objective signs of endemic malaria of all grades of severity, whilst epidemic phenomena constitute the expression of the reaction of the human body to parasitic invasions contracted in circumstances associated with inconstancy of infection. A sudden increase of infection due to some general determining cause, such as heavy rainfall and inundation of rivers and the associated high humidity at a time when the communal immunity is absolutely and relatively low, determines the genesis of epidemics.

Young and Majid (1930), in their study of malaria epidemics in Sind, attributed them to the combined effects of increased rainfall and high water level in the Indus, neither of which was exclusively operative in the production of epidemic malaria in that region. They also laid great stress on the economic factor influencing the severity of the epidemics.

Macdonald and Majid (1931), modifying Gill's views, showed that the lowered communal immunity was directly due to the presence of a large proportion of young children who had never been exposed to infection and were consequently non-immune. If in such a population the period favourable to transmission were sufficiently prolonged, they held that a fulminant epidemic would be produced.

Covell and Baily (1932) agree in principle to the rôle played by low communal immunity, high humidity associated with the excessive rainfall and flooding of rivers, and adverse economic conditions in the genesis of the Sind epidemics. They lay particular stress on the increase in the length of the period of high, sustained, relative atmospheric humidity as the main factor in the production of an epidemic of malaria. While the normal period of transmission in Sind according to them is not more than six weeks, they showed that it may be increased by about four weeks in years of excessive rainfall or flooding during the monsoon period.

In none of the views summarised above is any part attributed to the variations in virulence in different strains of the parasite or even the same strain of the parasite in the mechanism of epidemics.

Thomson (1933) concludes from a review of the experimental work on induced malaria that, after spontaneous recovery from benign tertian malaria, there develops an immunity to super-infection which, however, is only directed against the same strain of parasite since reinfection can be produced by inoculation with either another species of parasite or even a different strain of the original species, and that, therefore, the antibody formation is probably of a specific character. He further holds that proof is still lacking as to whether the resistance of persons with acquired immunity is due to the presence of latent infections or is in the nature of a true immunity, and that, although attempts to demonstrate the presence of protective antibodies have so far been unconvincing, the evidence derived from serological and other studies tends to support the view that such antibodies do exist.

In commenting upon the above, Gill (1933) remarks that the view that each species of malaria parasite embraces numerous strains possessing varying antigenic properties is somewhat startling and difficult to reconcile with observations made in India. While admitting that James's conclusions represent biological inferences drawn from precise experiment, he feels that they do not necessarily constitute a safe basis upon which to found conclusions of general epidemiological application since the experiments were made on human subjects (syphilitic) who are not normal and healthy, and who may have been administered during the course of malaria therapy numerous drugs such as arsenical preparations, sedatives and hypnotics whose influence on the malarial parasite is unknown. He would, therefore, apparently hold to his previous views that the intensity of malarial epidemics is not due to any exalted virulence of the parasite, but rather to the greater number of sporozoites injected by the vector species on account of its greater metabolic activity and longevity due to

favourable climatic conditions. He has also previously surmised that these conditions probably also affect the parasite in the human body, rendering them easier of transmission, though at the commencement of the epidemic no greater concentration of gametocytes has so far been demonstrated.

The Malaria Commission of the League of Nations (1925) quoted by Mulligan and Sinton (1933) have stressed the part played by the interchange of plasmodia resulting from mass movements of the people in the greatly enhanced malaria prevalence in Europe after the war.

It is not proposed in this paper to refer to the various experiments on superinfection and cross immunity with several strains of the different species of avian plasmodia.

Sinton and Mulligan (1933), after summarising them, adduce the following as evidence for the existence of different strains of human malarial parasite :

(1) Variations in the intensity or virulence of the clinical effects.

(2) Variations in their power to produce immunity or tolerance to the effects of superinfection with same or other strains of the same species.

(3) Variations in their reaction to therapeutic agents.

(4) Variations in their power to infect anophelines.

They further hold that the information available suggests that the original virulence of a strain of *P. vivax* may be altered by frequent passage through either the insect or animal hosts.

Let us now examine what evidence is furnished by the features of the present epidemic with regard to the question of changes in the virulence of the same or different strains of parasite from an epidemiological point of view.

The morbidity figures of Madakasira (Chart 2) show three distinct waves of progressively increasing amplitude at intervals of about four months. In Harpanahalli and Kudligi there are two well-marked waves at intervals of four months. Before the first great rise in the latter areas, however, there is a steady increase in the incidence of malaria for a number of months. Such steady and increasing natural inoculations for some months would serve to raise the communal immunity until a balance is reached between infection and communal resistance, if we postulate that different strains of malaria parasites with different antigenic properties do not exist. Such a balanced condition will not bring about a sharp rise in morbidity some months later and still less, a second and larger wave four months later, unless it is presumed that the first high wave is made up of children and the second of adults. Although the dispensary figures have not been analysed with reference to age, none of the medical officers noted any such marked incidence of the diseases in any special age group at any time.

On the other hand, the recorded features of the epidemic are consistent with the concept that continued facilities for transmission not only facilitated the introduction of the different strains of parasite but also tended to increase the virulence of the local strains by repeated passage into the human and insect hosts.

It may however be argued that the immunity engendered in fulminant epidemics partakes of the nature of an anti-toxic immunity rather than an anti-parasitic one, and therefore morbidity figures have little significance in

assessing the rôle of immunity. It has been shown above that the peak of mortality exhibits a distinct bimodal characteristic. If this bimodal peak was due only to the increased mortality in the earlier age groups representing the first peak and of later age groups representing the second, there will perhaps be no need to postulate the existence of different strains of parasite or of an increase in their virulence during the later phases of the epidemic. Chart 8 however shows distinctly that the earlier age groups also exhibit a well-marked bimodal mortality peak. It is therefore permissible to assume the occurrence of different strains of parasite which have better chances of propagation when the period of transmission is prolonged and also the occurrence of an increase in virulence produced by repeated passage through the human and insect hosts in series. While immunity plays an undoubted rôle in the genesis of malaria epidemics, on account of its specificity to species and strains of parasite, for all practical purposes, the 'threshold' of 'communal susceptibility' is very great especially when, as in the tropics, facilities for transmission are prolonged.

In commenting upon the early development of the recent Ceylon epidemic which was preceded by drought, Gill (1935) refers to the incidence of rain which occurred just before the onset of sickness. He adds that rainfall *per se* played no part in determining the onset of the epidemic, because, in certain areas, it occurred at a lesser interval than 20 days after rain fell. He therefore holds that the rise in atmospheric humidity, due to the sudden incidence of rain following upon a drought, precipitated the emergence of the epidemic, although increased rain might have flushed the breeding places in the river bed and necessarily checked the output of anopheline mosquitoes. He further holds that relapses brought about by the rise in the atmospheric humidity should have played an appreciable part in the opening phases of the epidemic, since, if the sudden onset of the sickness was mainly due to new infections, there should have been a sudden sharp rise in the number of deaths in children under 10 years within a week of the first emergence of the epidemic, which however was not found to be the case.

It is difficult to reconcile the above view with the conclusions of the Malaria Commission of the League of Nations (1933) with regard to the natural history of untreated malaria as recorded in their review of the 'Chemotherapeutics of malaria'. Ceylon experienced much less sickness from malaria for the four years prior to the epidemic than ever before, and, since relapses could only be a fractional function of the primary infections in the previous malaria season, it is not quite clear how in the opening phases of the epidemic there could have been such a large number of relapses, very much in excess of the fresh infections in the previous malaria season. Again, gametocytes in relapses are not so abundant as in primary attacks, and hence relapses do not facilitate transmission to the same degree as primary infections. On the other hand the absence of increase in the number of deaths in children is consistent with the view that to bring about a mortality in this susceptible population, at least one passage through the insect host is required to endow the parasite with sufficient virulence.

Macdonald and Majid (1931) and Covell and Baily (1932) have shown that although the crescent carriers may not be in great abundance in the commencement of the epidemic, they tend to be produced in large numbers in geometrical progression at approximate intervals of one month, which accounted for the rapid development of the epidemic when facilities for transmission are

prolonged. In this connection the density of population has no doubt a very great bearing. In the Punjab which is thickly populated, the time taken for what may be called 'a unit of transmission' is probably three weeks to a month. In Bellary and Anantapur districts on the other hand, where the density of population is only 163 per square mile, facilities for the gametocyte carriers to infect the mosquito on the one hand and for the infected mosquitoes to infect fresh human hosts on the other, will be much more limited; and this probably accounts for the lag of two to four months between increased incidence of rain and increased incidence of sickness in these areas. There are no records to show the longevity of mosquitoes in these districts, which have usually a low relative humidity. It may be that most of them die before they are able to transmit the disease, especially in view of the low density of population. Hence the normal period of transmission may be confined to a very short period in the year, which probably accounts for the very low spleen rate of 1 per cent in Madakasira in the inter-epidemic period. If the Ceded Districts had a very dense population, the full ravages of the epidemic would probably have occurred in a much shorter time, as in the Punjab. Conversely, if in the Punjab facilities for transmission are not brought to an abrupt end by climatological conditions, the epidemic would probably be longer in duration and possibly bring about an increased adult mortality as well, through the increase in the virulence of parasite by a greater number of passages through the human and insect hosts. These reflections are purely speculative, but they suggest certain lines of investigation into the normal period of transmission and the longevity of the mosquito in the Ceded Districts.

The above discussion has a great bearing on the method of control of malaria epidemics. Dealing with the technical control of epidemic malaria, Gill (1935) says that hitherto these epidemics have been regarded as uncontrollable. But there is now reason to believe that their emergence can be prevented. He holds that the measures to reduce the incidence of endemic malaria will also prevent the incidence of epidemics. He further holds that, if measures are taken that will reduce the spleen rate and the anopheline rate (*A. culicifacies*) in the main epidemic area to the levels found in the non-epidemic areas, no epidemic of appreciable magnitude can ever recur in the epidemic area, however favourable the meteorological and other conditions may be.

Young and Majid (1930) hold that apparently the only practical method of malaria control in rural Sind as indeed in the greater portion of malaria-infected districts in India is to improve the economic condition under which the people live, as has been pointed out by the Malaria Commission of the League of Nations. Sinton (1930), in commenting on this, states that the League of Nations' report refers primarily to European conditions in which the secondary factor of irrigation with its malaria-producing effect plays little or no part.

Covell and Baily (1932) hold that, as regards anti-larval operations, every effort should be concentrated on the breeding places of the carrier species, during the pre-epidemic period and the first few weeks of the epidemic.

Referring to the views that epidemics come and go without any notable change in the anopheline factor, and that the human factor (economic and demographic) was the principal determining cause, the Malaria Commission of the League of Nations (1930) stated that this conclusion may be correct but

that at present there were not sufficient data to show that the number of malarial vectors was less during non-epidemic years than in epidemic ones and that they occurred outside permanently malarious foci during non-epidemic years. But if this should prove to be otherwise, they added, and if the anopheline factor should prove to be a variable one, then the question whether it can be influenced or contracted becomes much more important, even if we are convinced that anti-larval works during epidemics are impossible because of the magnitude of the task. There always remains the alternative of limiting the work to endemic foci.

Before and during the Madakasira epidemic, facilities were made for the free distribution of quinine through village headmen, tahsildars, vaccinators and health inspectors in practically every village in the taluk. Altogether about 180 lb. of quinine were distributed in the taluk in an area with a population of 40,000 in the space of seven months from September 1933 to April 1934. This was no doubt hardly adequate to the needs of the people judging from the amount of sickness. But the main point to consider in the rural tracts is that, although we can make quinine available free of cost, unfortunately we cannot yet make the people resort to it in full. Hence, although adequate provision of free quinine should be the first programme in the control of rural epidemic malaria, yet because the people do not avail themselves fully of the treatment provided, it is necessary to find further practical means, if we are to mitigate the high mortality which will otherwise be brought about by the epidemic. More especially is this the case when facilities for transmission are prolonged over a number of months, and the disease has a tendency to develop in successive waves of increasing amplitude. Anti-larval measures during the early stages of the epidemic period, and throughout its duration, appear to be both required and useful, at all events, in the tropics and in the sparsely populated areas.

V. SUMMARY.

1. Instances of the occurrence of epidemic malaria are recorded in certain parts of the Madras Presidency, particularly in the Ceded Districts of Kurnool, Bellary, Anantapur and Cuddapah. These outbreaks were attended with high mortality and extended over several taluks. The epidemics were not brought about by 'any tropical aggregation of labour', but were associated with the high incidence of rainfall.

2. The features of a recent epidemic of malaria, which occurred in 1933-34 in Madakasira taluk in Anantapur district and in Harpanahalli, Hadagalli and Kudligi taluks in Bellary district, are described in detail.

3. This epidemic was associated with two consecutive years of unusually high rainfall.

4. Marked increase in rainfall was followed at an interval of not less than two months by an increase in the incidence of malaria. When there was high rainfall in two consecutive years, successive waves of malaria incidence occurred with a progressive increase in their amplitude and with greatly enhanced mortality effects.

5. Areas, in which a very low spleen rate was recorded in the inter-epidemic period, showed as high a spleen rate as 70 per cent at the height of the epidemic.

6. Infections with *P. vivax* and *P. falciparum* prevailed in equal proportions at the height of the epidemic. The parasite index was 45 per cent in children and 74 per cent in adults just after the height of the epidemic. The average parasite prevalence immediately following the height of the epidemic was 800 per c.mm. in children and 1,200 per c.mm. in adults. *P. falciparum* was prevalent in large numbers even in April.

7. *A. culicifacies, A. subpictus* and *A. stephensi* were the only three species of *Anopheles* recorded in a limited mosquito survey which was carried out. *A. culicifacies* was the only anopheline found infected.

8. *The highest mortality occasioned by the* epidemic was *175* per mille (monthly mortality rate). The mortality peak exhibits bimodal characteristics. It is not strictly autumnal in periodicity. The curve is asymmetrical, the rise gradual in the beginning but more abrupt just before the peak is reached, and the descent is at first abrupt and then more gradual.

9. All age groups exhibit greatly enhanced mortality, the age group 1 to 5 showing a tendency to the greatest relative increase. The earlier age groups show a distinct bimodal characteristic in their mortality peaks. The later age groups show it in some areas, but not in others where the peak occurs only towards the later phases of the epidemic.

10. The epidemic tended to reduce the birth rate in the year of occurrence to some extent and that in the year following to a considerable extent. On account of the high adult mortality occasioned by it the birth rate is still below normal even much more than eight months after the height of the epidemic.

11. The prevalent views on the genesis of malaria epidemics are summarised, and the epidemiological evidence furnished by the features of the present epidemic with regard to its genesis are analysed.

12. The occurrence of a virulent epidemic with considerable toxic effects after prolonged and increasing natural inoculations of the parasite, leads us to assume the possibility of (*i*) different strains of malarial parasites with varying antigenic properties, or (*ii*) of the same species acquiring increased virulence by repeated passage through the insect and human hosts, or (*iii*) more probably a combination of these. The occurrence of a bimodal peak of mortality even in the lower and more susceptible age group lends further support to this view.

13. In formulating measures of control, in addition to adequate arrangements for free distribution of quinine, the institution of anti-larval measures from the commencement of the epidemic and throughout its duration is advocated.

Acknowledgment.

I am greatly indebted to Lieut.-Col. C. M. Ganapathy, M.C., I.M.S., Director of Public Health, Madras, for his kind permission to publish this paper.

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MALARIA IN QUETTA.

AN ANALYSIS OF THE STATISTICS OF ADMISSIONS TO MILITARY HOSPITALS, AND THEIR CORRELATION WITH TEMPERATURE, HUMIDITY AND RAINFALL.

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[23rd March, 1936.]

THE accompanying statistics have been collected from various sources. Those of annual admissions and strengths of British Other Ranks from 1888 onwards were taken from a tabulated record in the office of the Deputy Director, Medical Services (D. D. M. S.), Western Command, which had been compiled by someone unknown to us.

The figures for 1918 were not included in the original table, but these were collected for us from the records in Army Headquarters, Simla, by the kindness of Major J. S. K. Boyd, R.A.M.C. This unique table was very nearly lost in the recent earthquake, but it was recovered and now several copies have been made.

The figures for monthly admissions from January 1926 to December 1934 were, for the most part, collected from hospital reports, or extracted from hospital records, by one of us (J. H. G.) while he was antimalaria officer. For certain years the total admissions obtained from these statistics do not agree with the totals given in the tabulated record in the D. D. M. S.'s office; these discrepancies, unfortunately, were not detected until after the monthly figures had been analysed. We do not think, however, that these discrepancies vitiate the correlations between monthly admissions and monthly temperatures and humidity.

Dr. S. L. Pramanik, Government Meteorologist, Karachi, very kindly prepared Table IV showing mean daily maximum and minimum temperatures and relative humidity at Quetta from January 1926 to December 1934. He also provided the figures of total annual rainfall in Quetta from 1888 to 1934.

The correlation coefficients were calculated from the grouped data (Reitz, 1924). As their significance was ascertained by using the 'Z' factor of Fisher (1934), Shepard's corrections (*vide* Fisher, 1934) were not used. 'Z' was obtained from the table given by Fisher (1934).

The graphs have been made in arithmetical logarithm form, partly to save space, and, in Graph B, to show at a glance the comparison between the proportional rise and fall of malaria admission rates, and admission rates for certain other diseases (*vide* Pearl, 1930).

Lieut.-Col. A. G. McKendrick has drawn our attention to the consideration of whether increases shown as equal in these graphs, for example 2 to 4 per cent and 20 to 40 per cent, are equivalent in nature. Can, for example, a rise from 2 to 4 per cent in 'enterica' rates be equivalent in nature to a rise of 20 to 40 per cent in malaria? This is a far-reaching consideration which we cannot investigate; but commend to others more competent to do so.

The terms 'B.O.R.' and 'I.O.R.', perhaps, require explanation for non-military readers. 'B.O.R.' is the usual army contraction for 'British Other Rank' meaning all British soldiers below commissioned rank. 'I.O.R.' is a similar contraction for 'Indian Other Rank' with a similar meaning; but admissions of Indian officers with Viceroy's commissions are included under the heading 'I.O.R.' in Indian military hospital statistics. The number of these officers admitted to Indian military hospitals is small in proportion to the numbers below commissioned rank, who are admitted to those hospitals.

In military hospital statistics, admissions for malaria are differentiated as 'fresh' and 'relapse'; benign tertian, malignant tertian, etc. Using the British and Indian military hospital statistics for mutual check, we have found that for the years 1932 to 1934 inclusive, the diagnoses of benign tertian malaria and of malignant tertian malaria recorded each month from the two hospitals are positively correlated (Table III); on the other hand we have found very wide variation between the diagnoses of 'fresh' and 'relapse' cases. Partly for these reasons, and partly because there was no differentiation in the annual figures given in the D.D.M.S.'s table, we have taken all categories of malaria admissions together in both monthly and annual statistics.

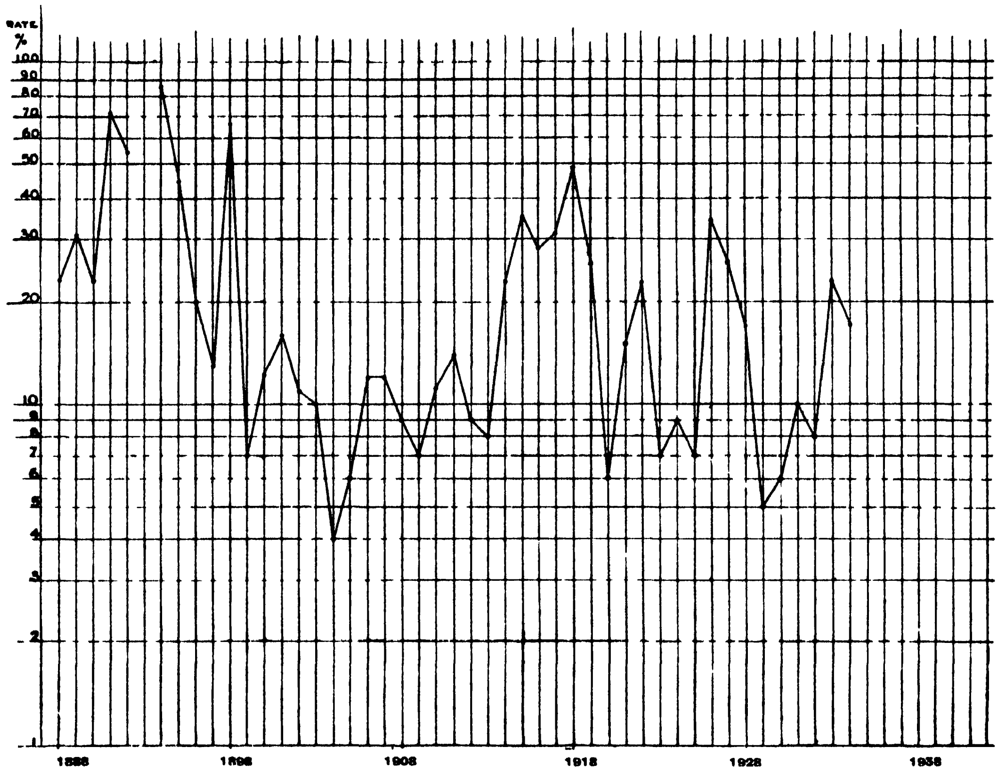
Another point, which we consider should be kept in mind, is that, although Quetta is taken as a unit in this paper, malaria admission rates from different barracks in the cantonment vary widely. The evidence for this we cannot give in this paper; but the fact has been established in official reports.

The trend of B.O.R. annual admission rates from 1888 to 1934 is given in Table I and in Graph A. From these it will be seen that the 47 years are divisible into three periods:—the first of 12 years, 1888 to 1899, in which the admission rate varies between 7 and 118 per cent; the third, of 21 years, 1914 to 1934, in which the admission rate varies between 5 and 49 per cent. These two are separated by a period of 14 years, 1900 to 1913, during which the admission rate only varied between 4 and 16 per cent. During this middle period of low admission rates for malaria, admission rates for 'enterica' disease fell from 5 to less than 1 per cent and the rate for 'all other causes' from 80 to 30 per cent; rates roughly the same as those now prevalent (Graph B). In comparing these three periods one must remember that since 1925, if not before, a steadily increasing majority of cases, classified as malaria, is so classified as the result of finding parasites in blood films. For example, out of the 593 B.O.R.

admissions for malaria in 1933 (Table I), 419 were classified as benign tertian and 159 as malignant tertian—classifications which regulations only allow to be recorded after positive microscopical findings.

GRAPH A.

Annual malaria admission rate per cent of B.O R.'s*, 1888 onwards (1893, 118 per cent).



* British Other Ranks.

It is vain to compare with too great nicety the statistics of distant years; but, as the rate in 1929 was 5 per cent, the rate, 4 per cent, for 1904 may not be too low. It is possible that influenza may have contributed to the high admission rates reported for malaria in 1893 and 1918 (Table I).

In recent years the treatment of breeding places, the use of nets by 'other ranks', and the fly-proofing of barrack rooms, probably made it more difficult for mosquitoes to bite humans in barrack rooms. Even when all these allowances are made, the figures do not suggest that a great reduction has been made in admission rates for malaria.

Table I, and item 6 in Table III, show that there is little relationship between rainfall registered in Quetta and annual admission rates for malaria among B.O.R.'s. This insignificant correlation may be due to the lack of

correspondence between rainfall registered in Quetta and the flood-producing rainfall on the distant hills.

The monthly statistics from 1926 to 1934 (Table II) show that the highest rates, particularly in the years with the highest incidence (1926 and 1933),

GRAPH B.

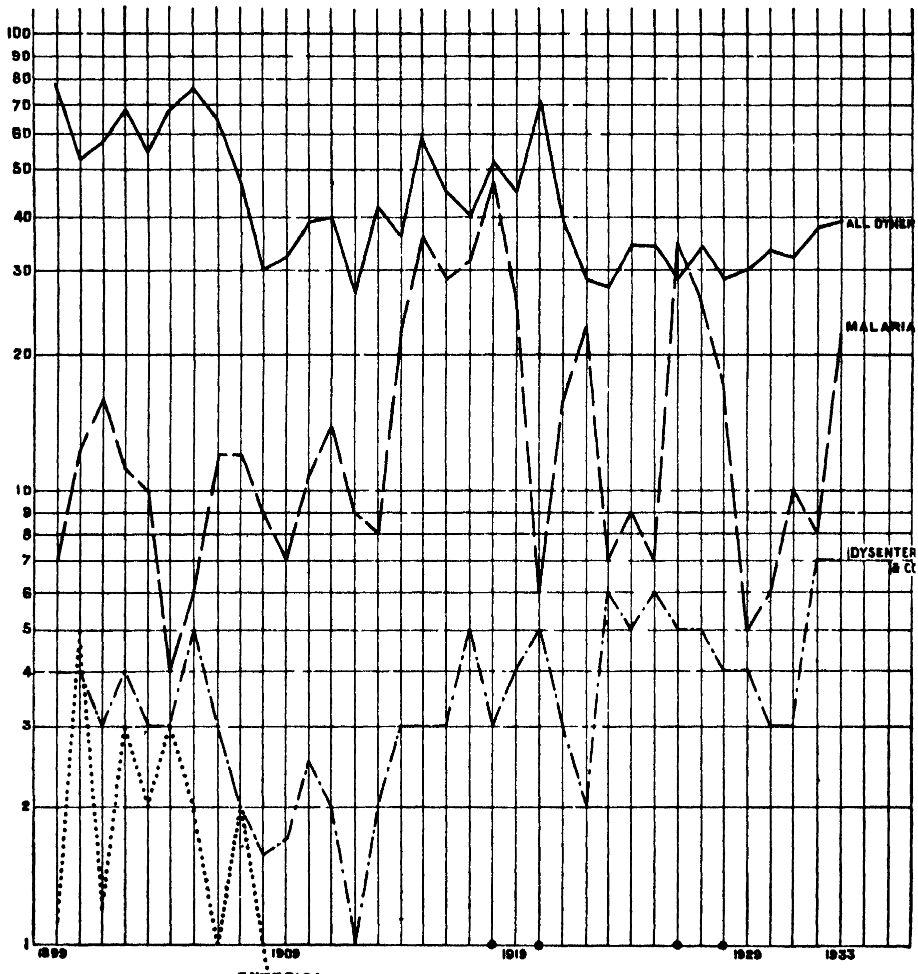
Quetta B.O.R. admission rates per cent, 1899 onwards.

Malaria

Enterica

Dysentery, diarrhœa, colitis

All other causes-



occur in September; the lowest rates in January, February or March. Except in 1929 (which had the lowest malaria rate, except 1904, since 1888), there was

a significant increase in the admission rate in May compared with the first three months of each year.

Relative humidity is negatively correlated with mean minimum temperature, with mean maximum temperature, and with monthly actual admissions for malaria (B.O.R. *plus* I.O.R.). The correlation coefficients of these three are significantly different from zero (Table III, serials 1, 2 and 3). Monthly actual admissions for malaria (B.O.R. *plus* I.O.R.) are positively correlated with both mean maximum and mean minimum daily temperatures. The correlation coefficients for these two are significantly different from zero (Table III, serials 4 and 5).

SUMMARY.

(1) Annual strength, and admissions for malaria, annual admission rate for malaria per cent of strength of British Other Ranks, and annual rainfall in inches from 1888 to 1934, are given in Table I.

(2) Monthly admission (B.O.R. *plus* I.O.R.) for malaria, annual average strength of these two classes, and the monthly admission rate per cent of the given strength, are recorded for the years 1926 to 1934 in Table II.

(3) Correlation coefficients, their 'Z', its standard error, and their significance for various pairs of statistics, are given in Table III.

(4) Graph A shows the trend of admission rates among B.O.R.'s for malaria from 1888 to 1934.

(5) In Graph B, the rise and fall of admission rates for malaria may be compared with those for enterica, dysentery, diarrhœa, colitis, and 'all other causes' (the percentage rate for the figure obtained by subtracting the three given diagnoses from total admissions in each year).

(6) The problem of whether increases in rates, numerically proportional, can be taken to mean that these increases are equivalent in nature, is commended for solution to those more competent than the authors.

(7) The classes of men, and the categories of malaria diagnoses included in the paper are defined, and reasons for not differentiating 'fresh' from 'relapse' and benign tertian from malignant tertian malaria are given.

(8) Attention is drawn to the fallacy of concluding that there is a uniform admission rate throughout Quetta Cantonment, and of placing too much reliance on conclusions drawn from a comparison of the older with the more recent statistics.

(9) An example is given of the high percentage (about 97 per cent) of malaria diagnosed microscopically in military hospitals.

CONCLUSIONS.

(1) The annual admission rates for malaria among British Other Ranks in Quetta are not significantly correlated with the annual rainfall registered in Quetta during the years 1888 to 1934.

(2) Monthly malaria admissions from 1926 to 1934, among British Other Ranks and Indian Other Ranks taken together, are positively and significantly

correlated with mean daily minimum and maximum temperatures; but negatively and significantly correlated with the relative humidity recorded in the mornings.

(3) Monthly admissions, during 1932, 1933 and 1934, of British Other Ranks for benign tertian malaria are positively and significantly correlated with the admissions of Indian Other Ranks for benign tertian malaria.

(4) There is a lower but still positive significant correlation between the admissions for malignant tertian malaria among British Other Ranks and among Indian Other Ranks during 1932, 1933 and 1934.

(5) These statistics give little evidence of effectual control of malaria in Quetta between the years 1888 and 1934, because, whatever may be ascribed as the cause of the low rates prevailing between 1900 and 1913, it ceased to be effectual after 1913.

We have to thank the Director of Medical Services in India for his permission to publish this paper; Lieut.-Col. A. G. McKendrick, I.M.S. (retd.), for his assistance and advice; the many people, not already mentioned, who have helped us in one way or another; and last, but not least, the unknown compiler of the statistical table maintained in the office of the D.D.M.S., Western Command.

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TABLE I.

Malaria in Quetta : B.O.R. strength, annual malaria admissions, annual malaria admission rate per cent, and annual rainfall, 1888 *to* 1934.

1	2	3	4	5
Year.	Average annual strength.	Annual admission for malaria.	Annual admission rate from malaria, per cent of strength.	Annual rainfall in inches.
1888	2,126	494	23·24	8·48
1889	2,140	668	31·21	7·77
1890	2,026	457	22·56	12·01
1891	2,137	1,540	72·06	13·03
1892	2,195	1,186	54·03	7·96
1893	2,098	2,475	117·97	13·95
1894	2,219	1,919	86·48	17·66
1895	2,354	1,053	44·73	7·84
1896	2,315	452	19·52	9·41
1897	2,307	300	13·00	9·53
1898	2,138	1,419	66·37	6·57
1899	2,405	167	6·94	7·33
1900	2,543	315	12·39	14·90
1901	2,446	389	15·90	5·00
1902	2,336	256	10·96	3·90
1903	2,447	246	10·05	11·71
1904	2,515	106	4·21	8·51
1905	2,590	162	6·25	15·05
1906	2,522	314	12·45	10·16
1907	2,663	318	11·94	8·77
1908	2,347	218	9·29	6·16
1909	2,927	199	6·80	8·31
1910	3,689	413	11·20	5·96
1911	3,391	465	13·71	12·45
1912	3,515	317	9·02	10·13
1913	3,460	263	7·60	9·51
1914	3,042	707	23·24	13·89
1915	2,868	1,011	35·25	4·41
1916	3,254	939	28·86	8·61
1917	3,182	977	30·70	8·68
1918	3,805	1,856	48·78	9·33
1919	1,925	498	25·87	6·35
1920	3,192	188	5·89	5·11
1921	3,128	482	15·41	5·96
1922	3,095	724	23·39	5·14
1923	2,593	181	6·98	7·71
1924	2,396	213	8·89	10·97
1925	2,523	165	6·54	4·02
1926	2,860	960	33·57	11·30
1927	2,503	662	26·45	5·40
1928	2,497	423	16·94	9·21
1929	2,490	113	4·54	6·98
1930	2,635	168	6·38	9·38
1931	2,665	274	10·28	10·96
1932	2,560	210	8·20	6·14
1933	2,577	593	23·01	9·96
1934	2,477	421	17·00	8·96

TABLE II.

Malaria in Quetta : monthly admissions, and admission rates per cent of annual strength British and Indian Other Ranks combined. January 1926 to December 1934.

Year.	Strength.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sep.	Oct.	Nov	Dec.
1926	11,355	Admissions	10	4	7	21	33	70	63	284	1.141	742	125	98
		Rate per cent	0·09	0·04	0·06	0·18	0·29	0·62	0·55	2·50	10·05	6·53	1·01	0·86
1927	10,783	Admissions	29	21	19	38	76	173	205	201	149	59	52	52
		Rate per cent	0·27	0·19	0·18	0·35	0·70	1·60	1·90	1·86	1·38	0·55	0·48	0·48
1928	10,395	Admissions	25	30	29	52	89	96	86	101	273	104	42	27
		Rate per cent	0·24	0·29	0·28	0·50	0·86	0·92	0·83	0·97	2·63	1·00	0·40	0·26
1929	10,138	Admissions	23	12	16	13	18	28	18	93	119	83	108	16
		Rate per cent	0·23	0·12	0·16	0·13	0·18	0·28	0·18	0·92	1·17	0·82	1·07	0·16
1930	10,403	Admissions	8	4	4	6	51	36	73	170	310	214	72	33
		Rate per cent	0·08	0·04	0·04	0·06	0·49	0·35	0·70	1·63	2·98	2·06	0·69	0·32
1931	10,146	Admissions	6	3	16	57	91	125	143	241	475	212	88	49
		Rate per cent	0·06	0·03	0·16	0·56	0·90	1·23	1·41	2·38	4·68	2·09	0·87	0·48
1932	9,945	Admissions	20	18	18	33	55	99	129	136	146	97	81	50
		Rate per cent	0·20	0·18	0·18	0·33	0·55	1·00	1·30	1·37	1·47	0·98	0·81	0·50
1933	9,492	Admissions	26	11	15	24	42	75	154	567	950	712	130	50
		Rate per cent	0·27	0·12	0·16	0·25	0·44	0·79	1·62	5·97	10·01	7·50	1·37	0·53
1934	9,250	Admissions	28	24	19	46	83	98	145	239	409	199	79	37
		Rate per cent	0·30	0·26	0·21	0·50	0·90	1·06	1·57	2·58	4·42	2·15	0·85	0·40

TABLE III.

Correlation coefficients for monthly and annual statistics of meteorological observations and admissions for malaria to military hospitals in Quetta.

1	2	3	4	5	6	
Serial.	Correlation between.	Correlation coefficient. r	Z	Standard error of Z. $1/\sqrt{n-3}$	Column 4 divided by column 5.	Note a.
1	Monthly mean relative humidity per cent at 0800 hours and monthly mean minimum temperature, 1926 to 1934.	—0·374	0·3930	1/9·5917	3·770	Significant negative correlation.
2	Monthly mean relative humidity per cent at 0800 hours and monthly mean maximum temperature, 1926 to 1934.	—0·536	0·5986	1/9·5917	5·741	Significant negative correlation.
3	Monthly malaria admissions (B. O. R. + I. O. R) and monthly mean relative humidity per cent at 0800 hours, 1926 to 1934.	—0·231	0·2352	1/9·5917	2·256	Significant negative correlation.
4	Monthly malaria admissions (B. O. R. + I. O. R.) and monthly mean minimum temperature, 1926 to 1934.	+0·4516	0·4867	1/10·0995	4·915	Significant positive correlation.
5	Monthly malaria admissions (B. O. R. + I. O. R.) and monthly mean maximum temperature, 1926 to 1934.	+0·5729	0·6518	1/10·0995	6·583	Significant positive correlation.

TABLE III—*concld.*

1	2	3	4	5	6	
Serial.	Correlation between.	Correlation coefficient. r	Z	Standard error of Z. $1/\sqrt{n-3}$	Column 4 divided by column 5.	Note a.
6	Annual B. O. R. admission rate per cent and annual rainfall in inches, 1888 to 1934.	+0·1472	0·1482	1/6·6332	0·9831	Insignificant positive correlation
7	B. O. R. monthly admissions for B. T. malaria and I. O. R. monthly admissions for B. T., Jan. 1932 to Dec. 1934.	+0·806	1·1154	1/5·7446	6·404	Significant positive correlation.
8	Between B. O. R. M. T. monthly admissions and I. O. R. M. T. monthly admissions, Jan. 1932 to Dec. 1934.	+0·600	0·6931	1/5·7446	3·982	Significant positive correlation.
9	Between B. O. R. + I. O. R. monthly admissions for B. T. and B. O. R. + I. O. R. monthly admissions for M. T., Jan. 1932 to Dec 1934.	+0·639	0·7565	1/5·7446	4·346	Significant positive correlation.

Note a.—Correlation coefficients have been taken to be significantly different from zero if their Z is twice its standard error as calculated in column 5 (after Fisher, 1934).

TABLE IV.

Statement showing the mean daily maximum and minimum temperatures and relative humidity and total rainfall amounts recorded at Quetta in each of the months during the period 1st January, 1926 to 31st December, 1934.

Year.	JANUARY.							FEBRUARY.						
	Temperatures, °F.				Relative humidity, per cent.		Total rainfall (inches).	Temperatures, °F.				Relative humidity, per cent.		Total rainfall (inches).
	Maximum.		Minimum.					Maximum.		Minimum.				
	Mean.	Highest.	Mean.	Lowest.	8 hrs. Local Time.	17 hrs. Indian Standard Time.		Mean.	Highest	Mean.	Lowest	8 hrs. Local Time.	17 hrs. Indian Standard Time.	
1926	50·8	60·4	28·0	22·3	(u) 82	..	1·78	57·9	71·1	32·9	26·0	(k) 82	..	1·78
1927	49·4	64·7	20·4	8·0	N. A.	..	0·71	48·5	58·9	27·1	14·1	(t) 87	..	2·02
1928	47·5	58·7	25·5	9·1	(s) 89	..	1·46	57·5	80·3	27·2	7·8	(s) 77	..	2·24
1929	51·7	69·3	26·8	11·2	N. A.	..	0·79	53·1	73·0	34·2	14·5	(n) 77	..	3·15
1930	43·3	55·0	30·8	20·0	(u) 75	..	2·59	57·0	71·0	30·5	16·0	(s) 67	..	0·80
1931	52·6	66·0	29·9	22·0	N. A.	..	2·22	44·9	57·0	29·0	19·0	N. A.	..	4·95
1932	58·0	75·0	29·8	13·0	56	..	0·41	58·4	69·0	27·4	17·0	44	..	0·64
1933	47·3	63·0	27·0	17·0	71	37	1·63	52·8	62·0	31·0	21·0	82	39	1·54
1934	38·7	56·0	16·3	6·0	N. A.	(o) 36	0·84	65·5	80·0	31·0	13·0	(m) 43	10	0·12

TABLE IV—*contd.*

Year.	MARCH. Temperatures, °F. Maximum. Mean.	Highest	Minimum Mean.	Lowest.	Relative humidity, per cent. 8 hrs Local Time.	17 hrs Indian Standard Time	Total rainfall (inches).	APRIL. Temperatures, °F. Maximum Mean	Highest	Minimum Mean.	Lowest	Relative humidity, per cent. 8 hrs. Local Time	17 hrs. Indian Standard Time.	Total rainfall (inches).
1926	60·5	72·3	35·4	24·6	(d) 81	..	3·09	68·3	79·7	39·4	30·4	46	..	0·73
1927	63·8	80·1	33·9	24·8	(j) 58	..	0·57	75·6	87·5	44·2	38·0	49	..	0·12
1928	63·4	74·1	35·7	18·6	(g) 71	..	2·86	81·2	89·4	45·7	36·0	52	..	0·18
1929	73·6	83·2	42·6	29·9	(e) 41	..	0·05	79·5	86·1	49·9	39·2	44	..	0·26
1930	64·7	78·0	37·4	25·0	67	..	0·49	72·6	83·0	46·5	35·0	55	..	2·19
1931	(b) 64·4	80·0	(b) 37·4	28·0	(b) 77	.	1·89	77·0	85·0	48·7	41·0	56	..	1·03
1932	65·1	78·0	40·6	28·0	67	..	1·23	78·1	88·0	47·8	39·0	45	..	0·29
1933	63·1	74·0	36·1	28·0	62	29	1·35	71·1	79·0	47·0	37·0	60	27	1·17
1934	62·2	72·0	36·6	23·0	(b) 57	24	1·08	76·1	85·0	47·6	36·0	37	12	0·33

TABLE IV—*contd.*

Year.	MAY. Temperatures, °F Maximum Mean.	Highest	Minimum Mean.	Lowest	Relative humidity, per cent 8 hrs Local Time	17 hrs Indian Standard Time	Total rainfall (inches)	JUNE. Temperatures, °F Maximum Mean	Highest	Minimum Mean	Lowest	Relative humidity, per cent 8 hrs Local Time	17 hrs. Indian Standard Time	Total rainfall (inches)
1926	80.9	90.3	50.7	44.3	59		1.63	89.8	95.1	53.8	47.9	40	..	0.0
1927	84.3	92.1	48.9	42.1	35	..	0.00	90.9	97.1	54.8	44.1	45	..	0.0
1928	87.3	93.5	51.3	39.3	43		0.23	93.8	99.9	57.3	49.5	43	..	0.0
1929	86.6	96.7	55.3	44.9	30	.	0.01	94.7	100.8	62.1	53.8	27	..	0.0
1930	86.0	93.0	53.8	46.0	37	..	0.03	92.8	99.0	61.9	51.0	39	..	0.50
1931	83.1	92.0	54.0	44.0	38	..	0.46	90.5	97.0	59.3	51.0	41	..	0.03
1932	83.8	97.0	54.0	39.0	36	..	0.38	93.2	99.0	62.2	53.0	30	..	0.0
1933	85.5	95.0	55.0	46.0	50	15	0.87	95.4	103.0	63.8	53.0	35	9	0.0
1934	81.6	92.0	54.1	45.0	35	13	0.16	93.9	102.0	65.3	53.0	40	16	2.66

TABLE IV—*contd.*

Year	JULY.							AUGUST.						
	TEMPERATURES, °F.				Relative humidity, per cent.		Total rainfall (inches).	TEMPERATURES, °F.				Relative humidity, per cent.		Total rainfall (inches).
	Maximum.		Minimum.					Maximum.		Minimum.				
	Mean.	Highest	Mean.	Lowest	8 hrs. Local Time.	17 hrs. Indian Standard Time.		Mean.	Highest.	Mean.	Lowest.	8 hrs. Local Time.	17 hrs. Indian Standard Time.	
1926	96·7	104·1	63·6	54·7	53	..	0·16	96·2	100·4	65·2	57·6	68	..	0·09
1927	96·0	101·9	66·1	57·3	63	..	0·88	95·4	100·1	62·2	49·5	68	..	0·0
1928	95·5	101·1	62·9	50·3	56	..	0·16	94·1	98·7	60·4	48·7	59	..	0·01
1929	93·6	100·5	68·1	59·5	50	..	1·92	91·7	96·2	61·8	48·6	45	..	0·0
1930	94·9	101·0	69·9	64·0	64	..	2·24	92·1	96·0	61·1	53·0	43	..	0·0
1931	94·6	100·0	66·4	56·0	51	..	0·05	98·3	103·0	67·1	55·0	58	..	0·0
1932	94·0	101·0	69·3	63·0	63	..	2·06	93·0	99·0	63·4	56·0	62	..	0·71
1933	96·3	103·0	68·1	57·0	57	19	2·50	92·9	97·0	68·0	62·0	67	22	0·56
1934	97·7	101·0	69·8	64·0	63	13	0·0	95·9	101·0	68·9	60·0	66	17	0·02

TABLE IV—*contd.*

Year	SEPTEMBER Temperatures, °F Maximum Mean	Maximum Highest	Minimum Mean	Minimum Lowest	Relative humidity per cent 8 hrs Local Time	17 hrs Indian Standard Time	Total rainfall (inches)	OCTOBER Temperatures °F Maximum Mean	Maximum Highest	Minimum Mean	Minimum Lowest	Relative humidity, per cent 8 hrs Local Time	17 hrs Indian Standard Time	Total rainfall (inches).
1926	87.7	94.3	52.6	35.2	69		0.67	75.9	87.1	33.0	27.4	(l) 67	..	0.0
1927	86.9	94.5	46.3	37.7	61		0.0	78.5	85.4	35.8	31.5	61	..	0.0
1928	85.8	92.1	44.5	34.8	55		0.03	77.8	83.6	40.9	30.5	(c) 30	..	0.0
1929	89.3	93.8	52.9	44.3	44		0.0	75.5	88.4	43.1	34.2	(b) 36	..	0.0
1930	86.8	94.0	51.1	36.0	36		0.0	75.2	87.0	43.0	32.0	(c) 45	..	0.18
1931	87.7	95.0	51.0	44.0	31		0.0	77.0	90.0	41.2	25.0	(n) 42	..	0.0
1932	87.5	94.0	52.3	45.0	33		0.0	74.1	82.0	39.2	25.0	30	..	0.0
1933	87.2	91.0	53.3	41.0	46	11	0.0	76.6	85.0	39.5	29.0	33	6	0.0
1934	87.1	93.0	50.2	43.0	28	7	0.0	74.5	86.0	38.9	27.0	(c) 28	7	0.0

TABLE IV—*concld.*

Year.	NOVEMBER. Temperatures, °F. Maximum. Mean.	Highest.	Minimum. Mean.	Lowest	Relative humidity, per cent. 8 hrs. Local Time.	17 hrs. Indian Standard Time.	Total rainfall (inches).	DECEMBER. Temperatures, °F. Maximum. Mean.	Highest.	Minimum. Mean.	Lowest	Relative humidity, per cent. 8 hrs. Local Time.	17 hrs. Indian Standard Time.	Total rainfall (inches).
1926	61·9	73·1	24·8	17·1	N. A.	..	0·05	53·5	65·2	27·1	22·4	N. A.	..	1·32
1927	67·2	76·2	27·1	18·9	(h) 72	..	0·0	56·1	68·6	29·4	19·5	(p) 75	..	1·10
1928	64·4	74·5	35·4	24·0	(r) 60	..	1·18	51·6	61·7	29·4	15·9	N. A.	..	0·86
1929	65·2	71·4	32·7	22·0	N. A	..	0·0	44·5	68·0	26·5	3·0	N. A.	..	2·72
1930	66·9	71·0	32·9	25·0	91	..	0·15	56·3	67·0	24·4	18·0	N. A.	..	0·21
1931	67·1	73·0	32·6	26·0	(v) 55	..	0·04	55·9	67·0	26·6	17·0	N. A.	..	0·29
1932	66·1	75·0	30·1	25·0	51	..	0·0	(b) 51·6	61·0	24·7	13·0	N. A.	..	0·42
1933	65·9	73·0	34·3	25·0	50	16	0·07	60·6	71·0	30·5	22·0	61	23	0·27
1934	64·0	75·0	33·2	24·0	(c) 47	16	0·0	56·7	74·0	35·0	26·0	77	43	3·70

NOTE I.
(b) = Mean of 30 days
(c) = „ „ 29 „
(d) = „ „ 28 „
(e) = „ „ 27 „
(g) = „ „ 25 „
(h) = Mean of 23 days.
(i) = „ „ 24 „
(j) = „ „ 22 „
(k) = „ „ 21 „
(l) = „ „ 20 „
(n) = Mean of 18 days.
(o) = „ „ 17 „
(p) = „ „ 16 „
(r) = „ „ 14 „
(s) = „ „ 13 „
(t) = Mean of 12 days
(u) = „ „ 11 „
(v) = „ „ 10 „

NOTE II. Highest values of maximum and lowest values of minimum given correct to the first place of decimal up to December 1930 and in whole numbers from January 1931 onwards.

NOTE III. Relative humidity at 8 hours Local Time only available up to December 1932 and 8 hours Local Time and 17 hours Indian Standard Time from January 1933 onwards.

Records of the Malaria Survey of India, 6, 2, June, 1936.

MALARIA IN QUETTA, BALUCHISTAN.

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[15th April, 1936.]

CONTENTS.

FOREWORD.

A PRELIMINARY reconnaissance of the malaria problem in Quetta was made by the senior author in May 1935, and, immediately after the conclusion of this short investigation, Quetta was devastated by a severe earthquake. As the result of the preliminary visit, it was fully realised that little was known with regard to the various factors influencing the spread of malaria in the Quetta area, and it was recognised that, if any consideration were to be given to the malaria problem during the reconstruction of Quetta, a more detailed investigation would be essential. The malaria survey on which this report is based, was carried out between 25th July and 9th October, 1935. During this period it was possible to obtain much information with regard to the epidemiology of malaria in Quetta. So little was known on this subject before this survey was commenced that we have been prompted to record the results of our observations in detail, in the hope that they will be of value to future health workers in this locality. We are fully aware of the very limited nature of our investigation, and of the many gaps in our knowledge of malaria in Quetta which still exist, but we are hopeful that this report may provide a starting point for much more detailed investigations.

We gratefully acknowledge the assistance of all those, both medical and laymen, whose aid facilitated this investigation. They are too numerous to name individually, but we should like to mention especially Lieut.-Col. J. A. Sinton, V.C., O.B.E., I.M.S., Director, Malaria Survey of India, for the great interest he has taken in our work, and for much help, advice and criticism in the preparation of this report.

We must also acknowledge the assistance which we have received from Covell's publications on the distribution and infectivity of the Indian anophelines, and from Christophers' volume on the Anophelini in the 'Fauna of British India' Series. Free use has been made of these invaluable publications.

I. INTRODUCTION.

1. BRIEF DESCRIPTION OF QUETTA.

Quetta, the capital of Baluchistan, is a large civil and military station lying 30° 10′ North and 67° 1′ East. It is situated on a bare open plateau measuring some 16 miles long and 8 miles broad, and having an average elevation of between 5,000 and 6,000 feet above sea level. The plain is surrounded by high mountain ranges which rise precipitously to heights of 10,000 feet and more (*vide* Map).

The Quetta valley is drained by the Sariab Lora which flows in a northerly direction about a mile to the west of Quetta town, and eventually discharges into the Pishin Lora. Quetta lies on the easterly slope of the valley which falls towards the Sariab Lora with an average gradient of about 100 feet per mile. About two miles to the north-west of the military station, the outfall of the narrow Hanna valley and of the Hanna river which traverses it, enters the Quetta valley. This river provides the main source of supply of both domestic and irrigation water for Quetta. Storm water from the Quetta area and from the hills to the east, is drained off chiefly in two main nullahs (the Durani and the Habib nullahs) which intersect Quetta from east to west, and eventually discharge into the Sariab Lora. Roughly speaking, the cantonment lies to the north of the Habib nullah, and the city and civil station to the south of it.

2. THE CLIMATE OF QUETTA.

The climate of Quetta is subject to moderate extremes of heat and cold. The mean monthly figures for temperature, humidity, rainfall, etc., are given in Appendix I. The seasons are well marked, the spring commencing about the end of March, the summer in June, the autumn in September, and the winter in December.

The day temperatures are high in July and August, but the night temperatures are always cool. The mean temperature in summer is about 78°F., and in winter about 40°F.

In the winter frosts occur, and snow falls are not uncommon, especially at the higher elevations. The total annual precipitation is variable but is generally in the neighbourhood of ten inches most of which falls between December and March. There is considerable variation in the amount of winter precipitation, and this has an important bearing on the yield of various water sources such as springs and artesian wells, during the ensuing warm season.

During the summer months Quetta is liable to one or more bursts of heavy rainfall with resultant scouring of various water channels and nullahs.

3. THE POPULATION OF QUETTA.

Quetta is the seat of one of the largest garrisons in the British Empire, the total number of troops stationed there being about 10,000. Of these, some 2,000 are British and the remainder Indian and Gurkha. Owing to the close proximity of the city, the civilian population of the cantonment is comparatively small, the city taking the place of the usual Sadar bazaar.

Since the constitution of a large garrison at Quetta, the civilian population has increased rapidly. According to the census of 1921, the population of Quetta

was 24,283, while in 1931 it had risen to 34,881. In addition to the population which is resident in Quetta throughout the entire year, there is a large influx of visitors during the summer months. Many of these summer visitors come from the Punjab and Sind, parts of which are highly malarious. At the time of occurrence of the earthquake in May 1935, it has been estimated that the population of Quetta amounted to upwards of 60,000.

4. OCCUPATION, TRADE, COMMUNICATIONS, ETC.

Besides being a large garrison, Quetta is the seat of the Baluchistan Administration, and the headquarters of the Quetta-Pishin district. There is, therefore, an aggregation of officials, government employees, police, etc. There is also a large railway colony as Quetta is a divisional headquarters of the North-Western Railway.

Since the British occupation of Baluchistan there has been a large increase in trade, as is shown by the figures for imports and exports. There are, however, no large industrial concerns in Quetta, the nearest approach to these being the Flour Mills and the Brewery. The latter is now virtually defunct.

Quetta lies on the main trade route between India and Afghanistan, and its increasing prosperity prior to the earthquake was probably largely attributable to the expansion of the Afghan, and to a lesser extent of the Persian trade.

The population of Quetta is largely a floating one. This is true not only of the military population, but possibly to an even greater extent of the civil population resident in the city. As many of the summer visitors come from malarious areas, and many of the traders and troops do likewise, there is every opportunity for the introduction of new strains of malaria parasites. While this is probably true, it seems likely that many of the inhabitants become infected with malaria during their period of temporary residence in Quetta. In other words it seems probable that Quetta exports as much, or more, malaria than is imported.

5. THE WATER SUPPLY OF QUETTA.

Quetta is dependent to a large extent upon the Hanna river for its supply of both domestic and irrigation water.

(*a*) DOMESTIC WATER SUPPLY.

At the present time the greater part of the drinking and domestic water supply for Quetta is brought in pipes from Urak to reservoirs situated above the Staff College, and is distributed in pipes to various parts of the area. This supply is derived from the Hanna river, and as the amount of water available in exceptionally dry seasons is said to be insufficient, a large reserve supply is maintained in the artificially constructed Hanna lake. A scheme is now in progress to augment the supply of domestic and drinking water in Quetta by constructing a dam across the Spin-Kareze valley from which the water collected will be passed into the Hanna lake. It is anticipated that, when this scheme is completed, the water supply to Quetta will be a continuous one, instead of an intermittent one as at present.

In the railway area the Urak supply is augmented by three tube wells, the water from which is pumped into high service tanks.

(*b*) IRRIGATION WATER.

In Quetta, water for irrigation purposes is obtained from three chief sources :—

(*i*) Irrigation channels from the Hanna river.
(*ii*) Karezes.
(*iii*) Natural water outcrops, including springs and artesian wells.

(*i*) *Hanna river water.*—It is said that at present the amount of water obtained from this source is insufficient, in ordinary years, to meet the demands. It appears to be confidently anticipated, however, that after the completion of the Spin-Kareze dam project, the reserve water in the Hanna lake will be augmented to such an extent as to permit of much of this water being used for irrigation purposes. It has been estimated that, in future, the irrigation supply from the Hanna valley should be at least doubled, and possibly trebled.

(*ii*) *Karezes.*—The kareze system of irrigation is not met with in most parts of India and merits a detailed description. This will be given below, when the breeding-places of anopheline mosquitoes are considered (*vide* p. 309).

(*iii*) *Springs and artesian wells, etc.*—The numerous springs and artesian wells which occur in certain parts of the Quetta area are important sources of irrigation water. These will be described more fully below when the local anopheline breeding-places are considered in detail.

II. THE HISTORY OF MALARIA IN QUETTA.

Little has been written with regard to the occurrence of malaria in the Quetta area, but such information as we have been able to obtain from the literature points to the fact that Quetta has been a very malarious place for many years.

Rae (1854) records that in August, September and October, 1840, there was a very high incidence of disease among the troops in Quetta. From the figures given it is estimated that on 16th September, 1840, the sick-rate among the troops of the garrison was about 312 per 1,000. The vast majority of the cases of sickness were probably due to malaria. This author quotes from Hough's 'Narrative of the Army of the Indus' that 'around the town of Quetta the water lies near the surface, and forces itself upwards by many springs which stagnate, and cause numerous small morasses. These, and the constant irrigation of the fields, may account for the *intermittent fevers* which always prevail at Quetta in the autumn'.

Hamilton (1905), referring to Quetta in 1879, states that 'Quetta, at the time I am writing about, was by far the most malarious place I have ever had the misfortune to be stationed in......'. The same author also states that, 'in 1879 fifty per cent of all the troops in Quetta were in hospital during the autumn months, and everyone who was there the year before said it was just the same that year'.

In the 'Army Medical Department Reports' (1885) it is stated that 'the highest ratio of prevalence of the malaria fevers was 1,117 9 per 1,000 in the Quetta district'. Seven fatal cases of malaria among the troops in Quetta were recorded in that year. It is stated in regard to Quetta that the health of the troops in the earlier part of the year was good, but about the end of May malarial fever began to increase in frequency, and was very prevalent in

August, September and October, at the end of which month health began to improve.

Hughes-Buller (1907), writing in the *Baluchistan Gazetteer* Series (written about 1905) mentions malarial fever first in his list of the most prevalent diseases of the Quetta-Pishin district. This author apparently recognised the occurrence of sporadic outbreaks of malaria from time to time because he states that 'a heavy winter rainfall always means a great increase in malaria'.

Davys (1912) records the results of an anopheline survey in Quetta which was undertaken in an attempt to account for the high incidence of malaria among the troops of the garrison. Stammers and Davys (1912) comment upon the very high incidence of malaria in a certain unit stationed in Quetta in August 1911. Browse (1922) reported briefly on the anopheline mosquitoes of Quetta.

Mansell (1931) has published statistics of malaria in the troops in Quetta for the years 1927 to 1930 inclusive. This author also gives interesting histograms of the meteorological conditions prevailing in Quetta in each of the above years, and attempts to correlate these and the movements of troops with the incidence of malaria in the Quetta garrison. Many interesting speculations are also made. According to this author, 'the questions which can be asked, to which there are, at present, no sound answers are innumerable, and in suggesting them, I am well aware of the attacks against which I am defenceless; but the answers to most, if not all of them, have a definite value in the prevention of malaria on this plateau. I can only plead that the experience of a single season, without any previous knowledge of the somewhat peculiar local conditions, and without previously existing organisation for dealing with such special problems, is insufficient on which to base any useful replies to these particular questions'.

An interesting and instructive report on malaria in Quetta cantonment in 1933 has been prepared by Captain J. H. Gorman, I.M.S. A definite epidemic of malaria is said to have occurred in this year. The highest admission ratio for malaria for any single unit of the Quetta garrison in 1933 was 811 per 1,000 The report, which is unpublished, gives useful military statistics, details of the mosquitoes caught and identified, and practical recommendations for the eradication or control of dangerous breeding-places within the military area.

The only statistics of malaria in Quetta which have been maintained for any lengthy period, and which have any claim to reliability are those for the troops of the Quetta garrison. A detailed analysis of these statistics has been undertaken in a separate paper by Molony and Gorman (1936) and will not be considered here.

Although malaria appears to have been excessively prevalent in Quetta for so long as written records go back, no intensive survey of the causative factors appears to have been undertaken prior to that on which the present report is based. Observations on the anopheline fauna of the Quetta area have been scanty, and the numbers caught and identified have been small. There are no records of dissections to determine the local malaria-carrying species, and no exhaustive study of their habits and breeding-places appears to have been undertaken. It is hoped that the data recorded in this paper may be regarded as a starting point in the detailed study of the epidemiology of malaria in this important civil and military station.

III. THE ANOPHELINE MOSQUITOES OF QUETTA.

A. GENERAL CONSIDERATIONS IN REGARD TO THE QUETTA ANOPHELINES.

In the investigation of the anopheline mosquitoes of Quetta, both larvæ and wild-caught adults have been studied. This was necessary to determine the malaria-carrying species, and the dangerous breeding-places. Besides, 'it is well known to workers in the tropics that a larval survey may give very different results, as regards the prevalent anophelines, from those which are obtained by a collection of adult mosquitoes in the houses' (Christophers and Missiroli, 1933). As will be shown in this paper such a disparity between the numbers of adults and larvæ collected in Quetta was only observed in relation to one species (*A. turkhudi*).

The anopheline mosquitoes of the Quetta area have been little studied in the past. For this reason, and because the local conditions are somewhat different from those prevailing in many parts of India, it has been thought advisable to attempt a detailed analysis of the mass of data collected during the survey. As much of this data is primarily of local interest, it has been decided to give a preliminary account of the anopheline fauna of Quetta in general terms, and to follow this with a more detailed consideration of each individual species. Particular attention has been paid to those species which have been proved to play a prominent part in the transmission of malaria in this area. The latter were, in fact, found to be the most prevalent species in Quetta during the period of the survey.

1. ANOPHELINE MOSQUITOES CAPTURED AS ADULTS.

(*a*) METHODS OF INVESTIGATION.

Owing to the almost universal demolition of human and animal habitations over large areas of Quetta following the earthquake, many of the types of resting-places in which adult anopheline mosquitoes are usually sought, were abolished. For this reason some difficulty was experienced in selecting 'catching stations'. The institution of anti-malaria measures, including the destruction of mosquitoes in both the adult and the larval stages, was an added difficulty in the selection of suitable catching stations. The choice of the latter was governed by a variety of factors among which may be mentioned :—

(*i*) Proximity to anopheline breeding-places of different types, *e.g.*, springs, river, irrigation channels, etc.

(*ii*) Proximity to known foci of high malarial infection.

(*iii*) Representation of various types of adult resting-places, *e.g.*, houses, tents, crude shelters, outdoor shelters, etc.

(*iv*) Representation of areas in which reconstruction or expansion might be considered.

Shortly after the commencement of the survey, apparently representative catching stations were selected and regular collections were commenced in them. At first, routine collections were instituted in seven different localities, but, of these, only four were retained throughout the whole period of the survey. At a later date regular collections were commenced in other places.

The highly abnormal conditions prevailing in Quetta immediately after the earthquake, included movements of the population within the area, the erection of hastily constructed shelters, and the abandonment of many of the properly

TABLE I.

Selected catching area.	Nature of chief breeding-places in vicinity (within ½ mile).	Nature of resting-places from which collections made.	Intervals at which visited and time spent in collecting at each visit.	Amount and nature of interference with collecting work.
Hudda village	Springs, karezes and Lora stream	Crude, temporary shelters occupied by humans and animals.	Regular; twice weekly; 3 hours	Many springs and their effluents controlled. Partial control of Lora stream.
Police and railway quarters.	Springs and karezes.	Tents and ruined buildings	Regular; twice weekly; 3 hours	Control of many breeding-places; insecticidal sprays.
Navagaon village	Irrigation channels (kareze, river), and impounded waters connected therewith.	Human and animal habitations, unaffected by earthquake.	Regular; twice weekly; 3 hours	None.
Kotwal village	Irrigation channels (river, kareze), and impounded water connected therewith.	Human and animal habitations, unaffected by earthquake.	Regular; twice weekly; 3 hours	Slight interruptions caused by objections of local inhabitants
Kareze shafts (Lora valley)	Lora stream, springs, seepages, and karezes.	Deep, dark, kareze shafts and tunnels.	Regular; twice weekly from 19-8-35; 3 hours	Partial control.
Kareze shafts (Hanna valley).	Hanna river and irrigation channels.	Deep, dark, kareze shafts and tunnels	Regular; once weekly from 19-8-35; 3 hours	None.
Hill caves (Hanna valley).	Hanna river and irrigation channels.	Dark, cool, caves in hillside.	Regular; once weekly from 3-9-35; 3 hours	None.
Hill caves (Lora valley).	Open kareze channel.	Dark, cool, caves in hillside	Regular; once weekly from 19-8-35; 3 hours	None.
Military area	Irrigation channels and kareze.	Tents and unoccupied barracks Stables.	Irregular * (discontinued).	Control of many breeding-places; insecticidal sprays.
Civil Lines	Habib nullah and miscellaneous.	Tents and ruined houses.	Irregular * (discontinued).	Intensive control of breeding-places in vicinity.
Civil Hospital	Habib nullah and miscellaneous.	Tents and ruined buildings.	Irregular * (discontinued).	Intensive control of breeding-places in vicinity.

* Regular collections discontinued on account of the scarcity of mosquitoes after control measures instituted.

constructed houses. For these reasons it was not always possible to carry out the adult collections in exactly the same situations at each visit. The collecting stations referred to in this report would, therefore, be more accurately described as 'collecting areas', although every effort was made to collect anophelines from the same type of resting-place at each visit. It is not considered that these minor variations appreciably affect the results obtained. The area surveyed was an extensive one, and each collecting area may be regarded as bearing a similar relationship to this large area as a single house would bear to an ordinary village.

Other factors were, however, of more importance in tending to vitiate the results obtained from the collection of adult mosquitoes. These included the intensive anti-malaria measures which were being carried out in some parts of the locality (anti-larval measures and the use of insecticidal sprays in temporary habitations such as tents), and the objections raised by the local inhabitants to the collection of mosquitoes in their quarters. Despite these handicaps much useful information was obtained from adult catches.

The plan adopted was to visit each collecting area at regular intervals (once or twice weekly), the same time (usually 3 hours) being spent by the same collector in each area. In this time an expert collector was able to obtain a representative catch from practically every part of the selected area. As has been mentioned above, only four of the catching areas originally selected were retained throughout the whole period of the survey. Others were discontinued, for various reasons, after a varying number of visits, while new ones were selected at later periods. Table I summarises the main features of the various catching areas or stations, visited at regular or irregular intervals during the survey.

(*b*) SPECIES OF *Anopheles* ENCOUNTERED DURING THE SURVEY.

The following species of *Anopheles* were captured as adults during the period of the survey :—

A. superpictus *A. dthali* *A. pulcherrimus* *A. sergenti* *A. multicolor*	Mediterranean element.
A. culicifacies *A. stephensi* *A. turkhudi* *A. fluviatilis*	Indian element.
A. lindesayi *A. subpictus*	Oriental element.
*A. habibi**.	

No specimens of *A. moghulensis* were captured as adults, although larvæ of this species were encountered on several occasions. All species of *Anopheles* hitherto recorded from the Quetta area were encountered during the survey, and,

*This is a new species of *Anopheles*, a detailed description of which has been published by Mulligan and Puri (1936). Morphologically this species is more closely allied to the Mediterranean species than to any of the Indian or Oriental ones.

in addition, *A. sergenti* was found. *A. habibi* has been described as a new species, but no other anopheline mosquito with which it could be confused has hitherto been recorded from Quetta.

An interesting feature of the anopheline fauna of Quetta is the admixture of the Mediterranean, Indian and Oriental elements. These have been classified above in accordance with the grouping given by Christophers (1933). Quetta is situated close to the eastern limit of distribution of the Mediterranean species, and to the western limit of distribution of the Indian and Oriental species.

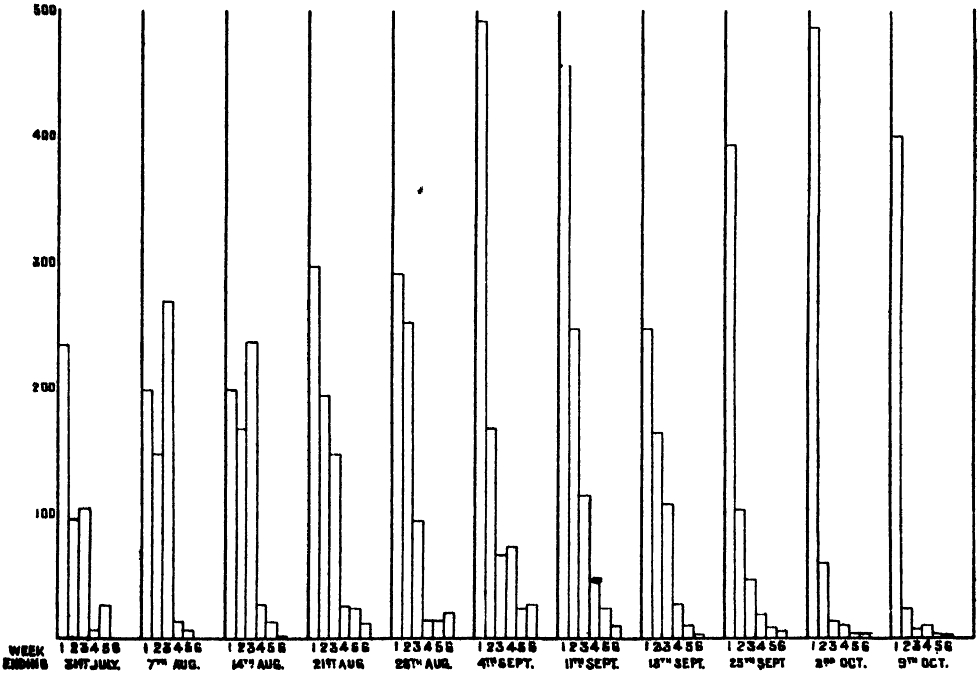
(c) Relative prevalence of anopheline mosquitoes in Quetta during the period of the survey.

Of the thirteen species of anopheline mosquitoes encountered in Quetta during the survey, only five were present in numbers which would be considered

Chart 1.

Showing seasonal prevalence of the six commoner species of *Anopheles*, by weekly periods, from July to October 1935 (wild-caught adults).

Actual numbers captured.



1. *A. superpictus*. 2. *A. culicifacies*. 3. *A. stephensi*.
4. *A. turkhudi*. 5. *A. dthali*. 6. *A. sergenti*.

sufficient to enable them to play any appreciable part in the transmission of malaria (*A. superpictus, A. culicifacies, A. stephensi, A. dthali* and *A. turkhudi*).

The remainder were present only in very small numbers and, on this account, cannot be considered as being of any practical importance in the epidemiology of malaria in this locality.

A total of 14,072 anopheline mosquitoes was identified of which 7,023 were captured as adults, and 7,049 were bred from larvæ and pupæ. It will be observed that, on the aggregate, the actual numbers of mosquitoes collected as adults and reared from larvæ correspond almost exactly. Furthermore, as will be shown later, the actual numbers of caught and bred adults of each species showed, with one exception, a very close numerical relationship.

The relative prevalence of the different species of anophelines in Quetta compiled from the records of adult catches is shown graphically, by weekly periods, in Chart 1.

(*d*) THE MALARIA-CARRYING ANOPHELINES OF QUETTA.

Dissections were made of the gut and glands of as many wild-caught anopheline females as was possible in the time available. The majority of these were carried out at headquarters in Kasauli. Those which could not be dissected in camp were despatched to Kasauli in Barraud's boxes. The practice was to dissect any feeble or moribund specimens first and to keep the remainder for several days so that, if they had only recently ingested an infective feed at the time of capture, there would be time for the parasites to develop sufficiently to ensure their detection at the time of examination. Despite a journey across the Sind desert during the hot season, the vast majority of the living anophelines despatched to Kasauli survived for 5 or 6 or more days after arrival, about 98 per cent being received in a condition suitable for dissection.

During the survey 3,044 anopheline females were dissected and examined for malarial infection. The results are summarised in Table II.

TABLE II.

Species of *Anopheles*.	Total number of adult females collected.	Number dissected.	Number infected.	Percentage infected.	Index of relative prevalence of wild-caught females.	Index of relative danger.
A. superpictus ..	2,327	1,412	69	4·9	2·3	11·3
A. culicifacies ..	1,327	835	44	5·1	1·3	6·6
A. stephensi ..	1,018	719	7	1·0	1·0	1·0
A. turkhudi ..	202	48	0	0·0	0·2	0·0
A. dthali ..	70	24	0	0·0	0·07	0·0
A. sergenti ..	49	6	0	0·0	0·05	0·0

The relative importance of the different species of anophelines in the transmission of malaria in a given area obviously depends on two main factors, namely :—

(*a*) The relative prevalence of the females of each species during the transmission season, and

(*b*) the percentage of infection occurring in each species.

The product of these two factors will indicate the relative potential danger to the community arising from each species ('Index of relative danger', *vide* Table II). In Quetta, only three species of *Anopheles* were found to be infected during the period of the survey, and the females of these three species were found to be present in the following proportions which have been estimated from the adult collections :—

A. superpictus 2,327.
A. culicifacies 1,327.
A. stephensi 1,018.

Taking *A. stephensi* as unity, it is clear that *A. culicifacies* and *A. superpictus* were 1·3 times and 2 3 times respectively as prevalent as *A. stephensi.*

The percentage of infections among these three species as determined by dissection was found to be 1·0 per cent, 5 1 per cent and 4 9 per cent in *A. stephensi, A. culicifacies* and *A. superpictus* respectively. The relative potential danger to the community from each of these species may therefore be stated as :—

A. stephensi 1·0 × 1·0 = 1 0.
A. culicifacies 5·1 × 1·3 = 6 6.
A. superpictus 4 9 × 2 3 = 11 3.

It must be remembered that different species of *Anopheles* may vary considerably in the type of resting-place in which they are commonly found. Thus a species, which may seldom be found in human habitations in the daytime, may be more prevalent than another which may be found in greater numbers in similar situations during the day. In Quetta, adult collections were made from a wide variety of situations including outdoor as well as indoor resting-places. It is thought, therefore, that the factors given as indicating the relative prevalence of the different species are fairly accurate. This is borne out by an analysis of the larval catches for the same area over the same period, which indicates that the relative prevalence of *A. superpictus, A. culicifacies* and *A. stephensi* was 2 0, 1 2 and 1 0 respectively. For the purpose of calculating this ratio, only larval collections which were made within one mile of the selected adult catching areas have been included.

Anderson (1930) employed a similar method of estimating what he has described as the 'infection danger factor' from anophelines in a given area. Davey and Gordon (1933) have proposed a formula for calculating the 'density of infective anophelines' in a given locality. In applying this formula it is necessary to know the total number of rooms examined, and another factor ('x') which represents the number of mosquitoes leaving the houses before dawn. Under the conditions prevailing in Quetta after the earthquake it was not possible to determine these factors accurately, though it is probable that the 'x' factor could be ignored since adult collections were made from both indoor and outdoor resting-places.

In the Quetta area during the malaria season of 1935, there is much evidence to show that *A. superpictus* was the most important malaria-carrying species, and that *A. culicifacies* also played a prominent part. *A. stephensi* was of much less importance. This generalisation applies to the Quetta area as a whole and does not necessarily indicate that the same order is maintained for individual sections of the community. On the contrary there is some evidence to suggest that, had it not been for the adoption of malaria control measures in certain

localised areas, *A. stephensi* might have proved to be a transmission agent of considerably greater importance.

(*e*) THE DIURNAL RESTING-PLACES OF ANOPHELINES IN QUETTA.

The conditions under which the inhabitants of the Quetta area were living, following the earthquake, may be considered as abnormal. Most of the human habitations had either been destroyed by the earthquake or were considered to be unsafe. Police, troops, civilians, railway employees, and many refugees were quartered in tents which were often pitched in the immediate vicinity of the former living quarters. In the neighbouring villages many of the survivors continued to live in close proximity to their ruined homes, sometimes in crudely constructed shelters, but sometimes with no more protection than the shade of trees.

The choice of resting-places for the local anophelines may therefore be considered to be somewhat different from those available under ordinary conditions in Quetta. While this may be true, the large number of anophelines caught in certain situations suggests that such places are probably usual ones, a probability which is supported by the finding of large numbers of anophelines in similar situations in those parts of the Quetta area which were little, or not at all, affected by the earthquake.

It is well known that different species of *Anopheles* vary somewhat in the selection of their resting-places. The most important physical character of a resting-place appears to be a considerable degree of darkness, though it is not necessarily the darkest place in which the largest number of anopheline mosquitoes are to be found. Other factors which may be of even greater importance to anophelines in the selection of resting-places are warmth, humidity, freedom from disturbance and proximity to suitable food supplies. The existence of suitable 'micro-climates' in a given locality may enable anophelines to live for longer periods than would be the case where such places did not exist.

After the ingestion of a blood meal, the choice of resting-places by anophelines is largely influenced by the factors mentioned above, and their movements are probably regulated by the existing conditions. If suitable resting-places are available in close proximity to the place in which a blood meal has been obtained there may be no incentive to seek shelter at greater distances, but if they do not exist close at hand, it may be necessary for anophelines to go further afield. As has been mentioned above, different species may behave differently in this respect.

During the period of the Quetta survey the diurnal resting-places of the anopheline fauna of the area were extensively investigated, and were discovered to include :—

(*i*) *Human habitations.*

Occupied.

(*a*) Houses in villages not affected by the earthquake.
(*b*) Tents occupied by troops, police, railway employees, hospital patients, refugees, etc.
(*c*) Crude temporary shelters hastily constructed on or near the sites of ruined villages.

Unoccupied.

(*a*) Bungalows, quarters, etc., vacated after the earthquake, but with the former inhabitants living in tents in their immediate vicinity.

(*b*) Barracks, etc., partially used during the day, but with the usual occupants sleeping in tents in close proximity.

(*ii*) *Animal houses.*

These were in all cases close to human habitations, and included cattle sheds in villages unaffected by the earthquake and in partially ruined villages, crude shelters in ruined villages, and stables in the Military Veterinary Hospital.

(*iii*) *Outdoor resting-places.*

Outdoor resting-places were found to include (*a*) deep, dark, cool kareze shafts and tunnels, and (*b*) caves in hillsides. Large numbers of anophelines were found resting in such situations some of which were in close proximity to human or animal habitations, while others were situated at a distance of half a mile or more from any such habitations. It is probable that these situations were highly suitable resting-places for anopheline mosquitoes, though the high concentration of anopheline mosquitoes in them might be explained by the scarcity of other suitable outdoor resting-places. In the Quetta valley there is a remarkable absence of vegetation such as would afford suitable shelter for anophelines.

The three chief malaria-carrying anophelines showed considerable differences in their choice of resting-places. The rough classification of the adult collections made in resting-places of different types (Table III) will serve to indicate the relative prevalence of each of the three carrier species in the various types of resting-places investigated.

TABLE III.

Species of *Anopheles*.	Resting-places in, or immediately adjacent to, human habitations.				Outdoor resting-places situated at some distance (usually ½ mile or more) from human habitations.		
	Villages unaffected by the earthquake.	Tents, ruins, vacant houses, etc.	Crude refugee shelters	Total.	Karezes	Caves.	Total.
A. superpictus ..	1,212	527	596	2,335	895	353	1,248
A. culicifacies ..	466	266	527	1,259	299	48	347
A. stephensi ..	69	175	875	1,119	78	3	81

While the numbers of the three species mentioned in Table III may be determined to some extent by the proximity of suitable breeding-places for individual species, there are considerable differences between the numbers of different species in indoor as opposed to outdoor resting-places which are not apparently attributable to this cause. Thus it will be observed that in the case

of *A. superpictus* a much higher proportion of adults was captured in outdoor resting-places than in the case of *A. culicifacies* although the breeding-places in closest proximity were often more suitable for the latter species. Similarly in the case of *A. stephensi,* the number of adults collected in outdoor resting-places was much smaller than of either of the other two species although suitable breeding-places for this species were often close at hand.

It was also observed that the relative prevalence of anopheline mosquitoes in indoor, as compared with outdoor, resting-places was variable with the season. Thus, while adult anophelines were numerous in outdoor resting-places in August, the numbers in the latter fell abruptly in late September, the fall in numbers being much more striking than was observed in indoor resting-places at the same time.

The adult anophelines collected in outdoor resting-places showed a lower proportion of newly emerged specimens than might have been expected. Many of the captured adult females showed evidence of having ingested a blood meal either by the presence of blood in the gut, the stage of development of the ovaries, or by the presence of malarial infection. Contrary to what might be expected, the highest percentage of infected mosquitoes was not necessarily found among the mosquito population found resting in or near human habitations. Infected specimens were not infrequently encountered in outdoor resting-places at some considerable distance (a quarter of a mile or more) from the nearest human habitation.

This subject will be discussed more fully when each individual species is dealt with in detail. A much more exhaustive study of this question is desirable than was possible during the period under review.

(*f*) The relative prevalence of male and female anophelines in the Quetta area.

Records were kept of the proportion of males to females both in the case of anophelines captured as adults and those bred from larvæ. The male to female ratio for individual species of anophelines is shown in Table IV.

It will be seen from Table IV that in the case of anophelines reared from larvæ the number of males and females of each species was approximately equal. This finding is in agreement with the statement of Christophers and Missiroli (1933) who, in reference to the number of males and females bred out from larvæ and pupæ obtained in nature, state that 'In all cases the number of the two sexes is approximately equal, but nearly always with the females slightly but distinctly in excess'. Mehta (1934) who has reviewed the literature on this subject and has added his own observations on three species of Indian *Anopheles,* reached a similar conclusion. It may be remarked that in our observations the number of males was sometimes slightly in excess of the females. The best example of this is to be seen in the case of *A. superpictus* where, out of a total of 3,156 adults which emerged from pupæ in the laboratory, 1,596 were males and 1,560 were females.

In contrast to the proportions of the sexes in bred specimens, the proportion of females among wild-caught adults was considerably in excess of that for males. This finding is in line with those of other workers [*vide* Christophers and Missiroli (1933)]. The latter authors state that :—

'The facts regarding the relative number of males appears to be largely explicable on the basis noted by Swellengrebel (1927), who points out that the

TABLE IV.

Species.	Adults captured in nature. Number collected.	Number of males.	Percentage of males.	Adults bred from larvæ. Number reared.	Number of males.	Percentage of males.
A. superpictus	3,683	1,356	37	3,156	1,596	50
A. culicifacies	1,606	279	17	1,512	720	48
A. stephensi	1,200	182	15	1,211	576	47
A. turkhudi	255	53	21	890	441	49
A. dthali	129	59	46	190	100	53
A. sergenti	78	29	37	14	8	
A. moghulensis	0	0		35	12	
A. multicolor	21	9		8	4	
A. subpictus	10	1		3	1	
A. pulcherrimus	20	0		9	6	
A. fluviatilis	13	2		10	6	
A. lindesayi	7	3		10	6	
A. habibi	1	0		1	0	
TOTAL FOR ALL SPECIES ..	7,023	1,973	28	7,049	3,477	49

males require only suitable shelter and not a blood meal, and so seek only situations suitable for shelter, irrespective of whether blood is available or not. Thus they tend to predominate in outlying shelters as against the interior of habitations and cattle sheds. The resting-places of the female are, however, commonly selected after a blood meal and tend to be in connection with the interior of habitations, cattle sheds, pigsties and other places where blood is available'.

It is probable that other factors play a part in the disproportion between the sexes in adult anopheline catches. It is generally believed that female anophelines live longer, at least under certain conditions, than the males, which therefore show a relative decrease. Under the conditions prevailing in Quetta during the survey, female anopheline mosquitoes were certainly surviving for considerable periods, as was shown by the occurrence of malarial infections, and the condition of the ovaries. Our observations tended to suggest that the proportion of females was influenced rather by proximity to breeding-places than by easy access to blood meals, for in some cases a higher proportion of males was observed in adult catches in human and animal habitations than among those from outdoor shelters situated a quarter of a mile or more from any evident source of blood meals. Another factor in the causation of the disproportion between the proportions of the sexes in adult anopheline catches may be the shorter range of flight of the male. Christophers and Missiroli (1933) quote the experiments of Swellengrebel who showed that on the reclaimed area of the Zuyder Zee the range of flight of the males was not inferior to that of the females. They point out, however, that 'flight in the case of the male might be expected to be less powerful than in the female, since the wing is narrower, less heavily scaled and seemingly less strongly developed. General experience also gives the impression that males are less widely disseminated from breeding-places than females'. This point is an important one from the

practical point of view since, as Christophers and Missiroli (1933) point out, the 'presence in any number of males usually indicates proximity or moderate proximity of breeding-places, with little obstruction to passage of the insects to the place where they have been caught'.

During the course of the survey, it was observed that the male to female ratio in the adult catches varied considerably for different species. Thus, in the case of *A. superpictus* the proportion of males was greater than in the case of either *A. culicifacies* or *A. stephensi.* This question will be discussed in more detail when individual species are considered.

(*g*) Dispersion and infiltration of anopheline mosquitoes in relation to Quetta.

The distances from breeding-places to which anopheline mosquitoes will disperse is a factor of extreme practical importance both in planning and carrying out malaria control measures, and in the selection of suitable sites for human habitations.

'In active dispersion, the outstanding point at issue is the distance which anophelines can cover by their own activities, either by a single flight or a succession of flights, in either case possibly aided by wind or special atmospheric conditions. Further, there has to be taken into account the possibility of a succession of flights interrupted by periods of rest or even of feeding on the way, leading to infiltration of an area or tract, a condition possibly not so common as may be supposed' (Christophers and Missiroli, 1933).

It is generally accepted that the distance to which anopheline mosquitoes will disperse varies directly with the extent of the breeding-places and the intensity of breeding in them. Much also depends on the proximity to the breeding-places of suitable sources of food and shelter. As a rule anopheline mosquitoes will only travel sufficiently far to obtain a blood meal and suitable resting-places. It is, therefore, profitable in many cases to provide protective barriers between human habitations and breeding-places. Such protective barriers usually take the form of animal houses which may afford adequate shelter and suitable food. In urban areas where suitable breeding-places for anophelines do not exist within the limits of the town, the central portion may be practically free from malaria whereas a high degree of malaria prevalence may be seen among the inhabitants of houses situated in the peripheral portions which are in closer proximity to dangerous breeding-grounds and to highly malarious foci. In this case the periphery of the town may be regarded as a protective barrier for the centre, by which the infiltration of dangerous anophelines is arrested. Such a state of affairs is well exemplified in the case of Quetta cantonment where the highest incidence of malaria is observed in those parts of the station which are situated close to the most dangerous breeding-grounds and the most highly malarious villages, namely at the periphery, while the more central parts are comparatively healthy. The larger the town or cantonment, the more marked will this difference appear, provided, of course, that mosquito breeding is absent, or controlled, within the urban area.

It is possible that the longer an anopheline mosquito lives after acquiring an infection, the further it will infiltrate, and the more people it will infect. Longevity of anophelines may, therefore, be an important factor in the causation

of severe outbreaks of malaria. While, in Quetta, it is probable that proper siting and adequate control measures would do much to prevent malaria during ordinary years, it could not be guaranteed that, in years which would be more favourable for an epidemic, it would be free from considerable exacerbations of malaria. In order to prevent the latter it would probably be necessary to extend the zone of control beyond that ordinarily found sufficient in years which are less favourable for the longevity of anophelines. Much good might also be accomplished by the use of insecticidal sprays for the destruction of adult anophelines.

Such information as can be given with regard to the dispersion and infiltration of the malaria-carrying anophelines of Quetta will be considered below when these species are dealt with in detail. As will be pointed out, this aspect of the malaria problem in Quetta requires much more extensive investigation than has been found possible during the course of a brief survey.

(*h*) Overwintering of the anophelines of Quetta.

As the survey of the Quetta area was terminated early in October, little first-hand information was obtained with regard to the method of overwintering of the local anophelines. The winter in Quetta (December to March) is a very severe one. Snowfalls are not uncommon and frosts occur. The mean maximum temperature in January is about 50°F., and the mean minimum about 28°F.

With regard to the malaria-carrying species, it seems probable that neither *A. stephensi* nor *A. culicifacies* overwinter in the adult stage, while, on the other hand, our observations suggest that *A. superpictus* enters on a stage of true hibernation. Adults of both *A. culicifacies* and *A. stephensi* showed a marked decline in numbers towards the end of September and were very scarce in the early part of October. On the other hand *A. superpictus* adults were still abundant at the conclusion of the survey, and many showed an increase in fat body, and arrest of ovarian development.

It appears likely, from our observations, that the method of overwintering of the Quetta anophelines may vary according as to whether the species concerned are Oriental or Mediterranean ones. The whole question requires detailed investigation as it might possibly have an important bearing on the control of malaria in this area.

2. THE BREEDING-PLACES OF THE QUETTA ANOPHELINES.

(*a*) General description of breeding-places.

The actual and potential mosquito breeding-places in and near Quetta may, for the purposes of a general description, be classified as :—

(*i*) Rivers and streams.
(*ii*) Irrigation channels.
(*iii*) Karezes.
(*iv*) Natural water outcrops.
(*v*) Sullage and storm-water channels.
(*vi*) Rain-water collections.
(*vii*) Miscellaneous.

(i) *Rivers and streams.*

Only two rivers have any direct bearing on the malaria problem in Quetta, namely the Hanna river and the Sariab Lora.

The Hanna river arises in the hills and, after flowing through the narrow Hanna valley, enters the Quetta valley to the north-east of the cantonment about two miles above the Staff College. The Hanna river is the source of the domestic water supply for Quetta, as well as of the main irrigation water supply for the cantonment and the cultivated land to the north of it. An investigation of the mosquito breeding in connection with the Hanna river was undertaken for several reasons, among which may be mentioned the complete absence of anti-malaria measures, the selection of suitable sites for the reconstruction of Quetta, the occurrence of military camp sites in its vicinity, and the possible effect of this river on the incidence of malaria in Quetta. Although it is not considered that mosquito breeding in the Hanna valley has any appreciable direct effect on the incidence of malaria in Quetta, much useful information was obtained from a study of the intense anopheline breeding which was found to occur in the river itself, and in irrigation channels arising from it.

The Sariab Lora (Lora stream) drains the Quetta valley, and flows in a northerly direction roughly parallel to, and about a mile to the west of, the main railway line which runs through Quetta. The Lora has a more direct effect on the incidence of malaria in the Quetta area than has the Hanna river, from which it differs in several important respects. While the Hanna river ripples over a shallow stony bed and runs in several small streams which, for the most part, are fairly rapidly flowing, the Lora is confined mainly to a single channel. This lies between steep banks, is more sluggish, has a less stony bed, and is richer in gross vertical vegetation such as grass, weeds, rushes, etc., than the Hanna river (*vide* Plate III, fig. 1, and Plate IV, fig. 4).

A thorough investigation of the anopheline breeding-places in the vicinity of the Lora stream was undertaken owing to its proximity to Quetta and to military camp sites, as well as on account of its importance in relation to the choice of sites for reconstruction and expansion.

(ii) *Irrigation channels.*

In the Quetta area irrigation water is derived mainly from three sources :—

(1) River water.

(2) Karezes.

(3) Springs and wells (artesian and tube wells).

Irrespective of the source from which it is derived, water for irrigation purposes is usually conducted in open earth ('kutcha') channels. These channels, especially when overgrown with grass and weeds, and when containing Spirogyra, breed anopheline mosquitoes in vast numbers. Even in those in which, owing to the gradient of the country, the velocity of the flow is as much as 2 miles an hour, breeding may take place in bays and backwaters along the edges. In those in which the flow is less rapid, breeding occurs more extensively, and where leaks and seepages occur breeding is, as a rule, most intense. In many of these channels, which are numerous in and around Quetta, the flow of water is continuous. Except in regard to the source of the water,

irrigation channels in the Quetta area are very similar to those in many other parts of India. In the case of those arising from karezes, however, the channels may sometimes be confined between steep banks.

(*iii*) *The kareze system.*

As the kareze system is unfamiliar to most malariologists, and as it is apparently of considerable importance in relation to the malaria problem in Quetta, a description of this method of irrigation is given below.

A kareze may be described as a series of perpendicular shafts, the bottoms of which are connected by a continuous unlined tunnel. By this means, subsoil water is collected and eventually brought to the surface where it is used for irrigation purposes. At the head of a kareze the shafts, which are sunk in order to facilitate the removal of earth in constructing the tunnel, may be very deep—often as much as fifty feet or more. As one proceeds from the kareze head, the depth of the shafts gradually decreases until the tunnel emerges at the surface and becomes an ordinary open irrigation channel. It is a popular belief that the water flowing in a kareze is derived from underground springs, but, according to Oldham (1892) this is seldom the case, and in most instances a kareze is merely a subsoil drain. The kareze system in Quetta has been investigated and described by Oldham (1892) from whose paper the following diagram and quotations have been taken.

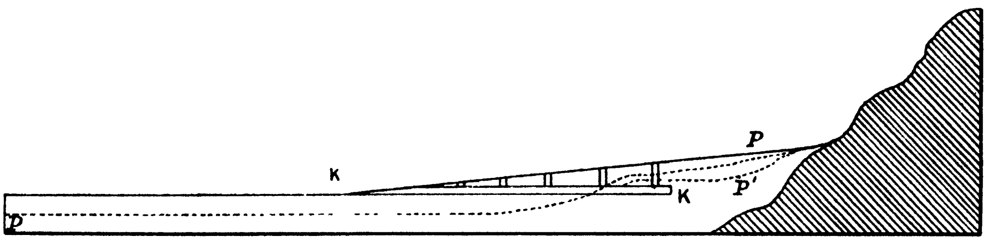


Diagram to illustrate the theory of the kareze (after Oldham)

'In figure 1 a diagrammatic section of one of the gravel slopes is represented; the dotted line *p.p.* represents the limit of permanent saturation, that is the limit below which the gravels are charged with water even in the driest season. Such a limit exists everywhere, but the form of its contour depends on a variety of conditions, such as the rainfall, discharge of streams at the head of the fan, permeability of the gravels, etc., which need not here be considered in detail. Now, if the karez *k.k.* is driven into this slope, that portion of it which lies below the line *p.p.* will drain the subsoil of its water and discharge this at the outlet'.

'It will be seen from this that in its nature and mode of action the karez is only a subsoil drain; in both cases the object is to bring water which lies underground to the surface, the only difference being that in one case it is desired to obtain the use, and in the other to get rid, of the water'.

'From the nature of the case these karezes are affected by the rainfall in a marked manner—a single dry season, and still more a succession of years of deficient rainfall, causes a diminution in the discharge of the karez......'.

'When the karez *k.k.* in figure 1 is first made, water will flow freely into it from the surrounding gravels in all that portion which lies within the original limit of permanent saturation. But, after it is completed, a new outlet is provided for the subsoil water, the limit of permanent saturation will adapt itself to the new conditions, and ultimately settle down with a profile which may be represented by the line *p.p′.p.* The subsequent history of the karez will now depend on the relative importance of the causes which led to the sub-soil water originally maintaining its level along *p.p′.p.* If the gravels were tolerably permeable and a considerable supply of water was constantly percolating through them, the karez will settle down to a fair or abundant discharge. If, on the other hand, the amount of water percolating was very small and the level of saturation kept up by the impermeability of the gravels, the ultimate conditions of the karez will be one of very small discharge........'.

'The amount of labour spent on some of these karezes, and the depth of their numerous shafts, is astounding; they are frequently miles in length and the shafts near their heads are said to be in some cases 150 feet deep. This is doubtless an extreme case, but, when examining the Quetta plain, I found that in many cases the shafts at the head of those which drain from the hills, east of the valley, could not be plumbed with the 70-feet line I carried with me'.

Karezes are very numerous in the Quetta area. Some of them yield a continuous, and surprisingly abundant, flow of water, while others may supply little or none.

Special attention was directed to the influence which the kareze system may exert on the malaria problem in Quetta. Mention has already been made of the importance of kareze shafts and tunnels as resting-places for adult mosquitoes. The suitability of kareze water for anopheline breeding varies considerably according to whether the channels are fully exposed to direct sun-light, or whether they are mostly open or underground, as will be shown below.

(*iv*) *Natural water outcrops.*

From the malaria point of view, perhaps the most remarkable feature of the Quetta plain is the occurrence of numerous natural water outcrops. These outcrops are variable in their size and nature, and have been observed to vary from seepages and small marshy spots to strong springs and artesian wells.

In some instances water may appear at the surface in low-lying areas, or in actual depressions. In such situations the water tends to collect into pools or ponds, and not infrequently the influx of water is indicated by the constant motion of the mobile quicksand which forms the bottom. Springs of the latter type are well exemplified in Forest Spinney which adjoins the Quetta Race Course. The largest spring of this nature which was encountered (over an acre in extent) is situated about midway between the Race Course and the Lora stream, and is known locally as the Baleli spring.

In other places, the water may make its appearance on the crest of relatively high ground, in which case it tends to trickle down the sides of the elevation, thus creating a shallow marshy area. A good example of this is seen in what is locally known as 'Five Springs'.

The part of the Quetta area where these outcrops of water are most numerous lies between the railway and the Lora stream, extending from the Habib nullah southwards to beyond Galbraith Spinney. The water issuing

from the numerous springs in this locality, as well as that from artesian and tube wells, is collected and distributed in open earth ('kutcha') irrigation channels. Small storage tanks or reservoirs are not uncommonly associated with the latter.

In certain parts of this area, one encounters deep cracks or fissures in the ground in some of which water appears at the surface. Places of this nature are most numerous in the relatively low-lying ground in the vicinity of the Lora stream.

A fuller description of individual anopheline breeding-places associated with natural outcrops will be given below when the breeding habits of the malaria-carrying anopheline mosquitoes of the Quetta area are considered in greater detail.

(*v*) *Sullage and storm-water channels.*

Quetta is traversed from east to west by two large nullahs—the Habib nullah and the Durani nullah. These two nullahs carry off most of the storm water after heavy rainfall. The Habib nullah formerly received the sullage water from Quetta city, and was so foul and dirty as to render it safe from the malaria point of view. Since the occurrence of the earthquake, there is no longer any sullage water from the city which is now uninhabited. The Habib nullah now, however, receives the outflow of clean water from the Kasi kareze, with the result that anopheline breeding in the nullah bed is intense where uncontrolled by anti-malaria measures (*vide* Plate V, fig. 6).

In dry weather the Durani nullah usually contains no water but, since the earthquake, excess irrigation water from the Hanna supply has been discharged into it at intervals, with the result that anopheline breeding has occasionally been observed in it. This was, for the most part, controlled by anti-larval measures during the period under review.

Sullage water from the cantonment is conveyed in 'pukka' (concrete) channels to the cantonment boundary, and thence in open earth ('kutcha') channels to the fields, where it is employed by the local zamindars for irrigation purposes. Little evidence of anopheline breeding has been found in this sullage water, although it was usually much less foul than that formerly coming from the city. In general it may be said that, before the earthquake, sullage water both from the city and the cantonment was so polluted as to be unsuitable for breeding dangerous anophelines. After heavy rainfall, however, this sullage water might be sufficiently diluted to render it suitable for anopheline breeding, especially where overflows had occurred.

(*vi*) *Rain-water collections.*

Owing to the complete absence of rainfall during the period of the survey, no opportunity was afforded of estimating the possible dangers from the collection of rain water, or of the results of flooding. There are numerous depressions and borrow-pits in and around Quetta, and to the south of the city there are large excavations resulting from brick-making operations. Although no first-hand information was obtained on this question, there is some reason to believe that water standing in such places after rainfall would considerably increase the amount of anopheline breeding in the Quetta area. In one instance where water from a leaky irrigation channel had accumulated in a borrow-pit anopheline breeding of the most incredible intensity was observed.

(*vii*) *Miscellaneous breeding-places.*

In addition to the breeding-places already mentioned, other potential anopheline breeding-places include wells, cisterns, open concrete tanks, elevated storage cisterns, cooling tanks for engines, water collections arising from open or leaky taps, etc. No evidence was obtained that any of these places were the source of any extensive anopheline breeding. Intense anopheline breeding was, however, observed in subsoil water in cracks and fissures in the ground, and in certain marshy areas (seepages) unconnected with any of the various water systems already mentioned.

(*b*) Methods of investigation employed.

During the preliminary survey in May the various potential breeding-places for anopheline mosquitoes were ascertained by walking over the whole area. When the main survey was commenced in July, it was possible from the outset to undertake a systematic investigation of the various breeding-places. These were classified as under :—

(*i*) The Hanna river and irrigation channels, etc., arising therefrom.
(*ii*) The Lora stream and irrigation channels, seepages, etc., associated therewith.
(*iii*) Natural water outcrops (springs) and irrigation channels, storage reservoirs, etc., arising therefrom.
(*iv*) The kareze system.
(*v*) Artesian and tube wells and irrigation channels arising therefrom.
(*vi*) Miscellaneous breeding-places.

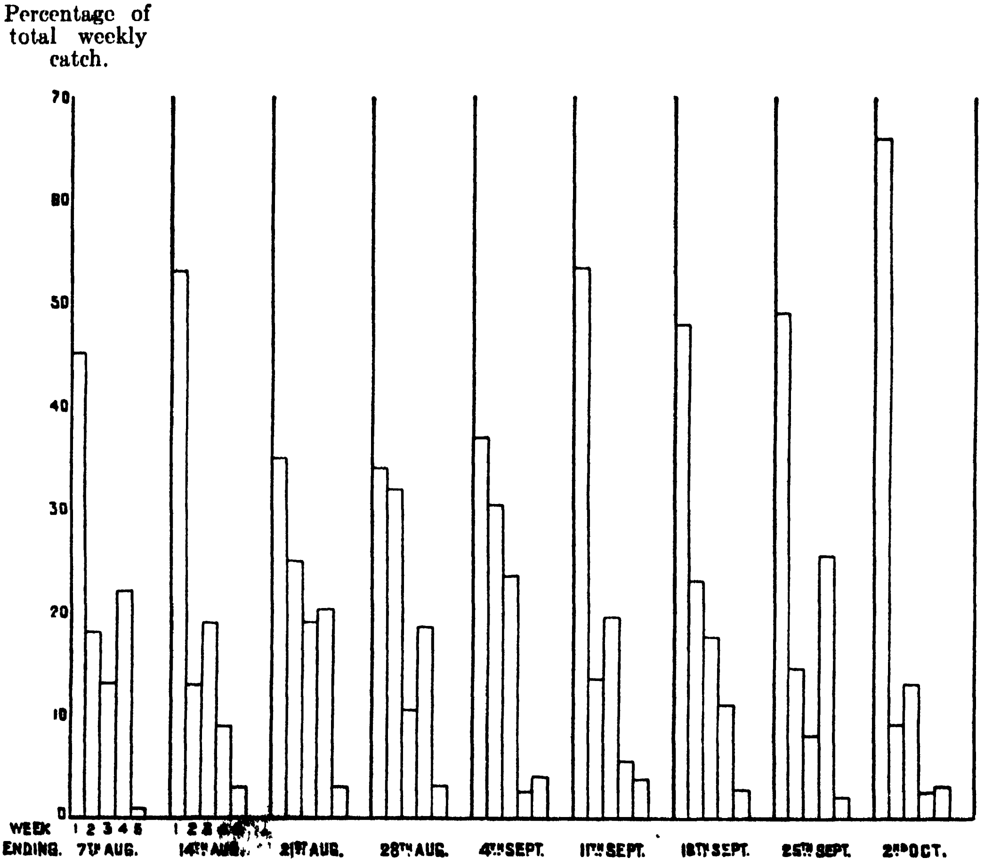
The plan of investigation adopted was to visit the different breeding-places as classified above on one day of each week, and to spend approximately the same time, with the same staff, in collecting larvæ from each. It was hoped that the results obtained from the 'random samples' taken at each visit would, in this way, be capable of detailed and simple analysis. The classification of breeding-places adopted enabled this scheme to be conveniently executed without any undue wastage of time in transit. Exceptions to this rule were the miscellaneous breeding-places, which in actual practice were visited as found convenient.

The actual time spent in collecting larvæ from breeding-places of the different types classified above, remained constant for any given week, but as time had to be found for other pressing work, the time allocated for the collection of larvæ during the early weeks of the survey was somewhat greater than in the later weeks. For this reason the results of the weekly larval catches of each species during the survey have been expressed as percentages of the total larval collection for each week, instead of the actual numbers collected, as has been done in the case of adult collections (*vide* Chart 2). It is considered that the actual numbers of larvæ collected from one breeding-place as compared with another, is a fair, though rough, indication of the amount of breeding going on in these places. In the analysis of our results we have preferred, therefore, to give actual numbers rather than to record the impressions gained. In point of fact the numbers given coincide in a remarkable way with the impressions gained as to the relative intensity of anopheline breeding in different places, and with the notes made at the time of collection. Furthermore, there is a very close correlation between the actual numbers of

anophelines reared from larvæ and pupæ and the numbers collected as adults, a finding which suggests strongly that the larval collections indicate with considerable accuracy the intensity of breeding in different places. The actual numerical prevalence of anopheline larvæ in any given breeding-place is, of course, governed by the extent of that breeding-place, rather than by the intensity of breeding in any given part of it. It was not found possible, under the conditions of the present survey, to attempt to estimate with any degree of precision the total extent of breeding-places of different types, but the results obtained by the method of investigation adopted probably give a fair representation of this.

CHART 2.

Showing the relative prevalence of larvæ of the five commoner species of *Anopheles* in Quetta, by weekly periods, from July to October 1935. Total number of specimens identified—6,869.



1. *A. superpictus*. 2. *A. culicifacies*. 3. *A. stephensi*. 4. *A. turkhudi*. 5 *A. dthali*.

With regard to the *relative* prevalence of the larvæ of different species of *Anopheles* in any given breeding-place, it is thought that the methods adopted afford the most reliable obtainable index of the preferential breeding habits of the various species of *Anopheles* encountered during the survey.

In a breeding-ground of any particular type 'random samples' of the larvæ present were taken, placed in separate tubes or bottles, and carefully labelled. At the same time a description of the breeding-place was entered in the field book under the corresponding serial number. It was not found possible to spare the time to identify the larvæ collected. On returning to camp, the procedure adopted was to place the larvæ collected from different breeding places in separate breeding-cages, and leave them to hatch out. So far as possible full-grown larvæ and pupæ were collected so that the mortality was practically negligible,* and the time required for hatching was reduced to a minimum. As they emerged, adults were caught and pinned twice daily, and subsequently despatched to headquarters at Kasauli for identification. In this way it was possible to conserve much of the time of the personnel working in the field. The identifications of the bred adults could also be made with greater accuracy than would have been possible by the cursory examination of larvæ in camp.

(*c*) The breeding-places of the three chief malaria-carrying anophelines of Quetta.

A general account of the chief anopheline breeding-places in the Quetta area and of the methods employed in making the larval collections have been given above. In this section it is proposed to describe in some detail the breeding-places of the three chief malaria-carrying species (*A. superpictus, A. culicifacies* and *A. stephensi*). The breeding habits of the remaining species will be considered when each of these species is dealt with individually.

The actual numbers of each of the three chief malaria-carrying anophelines which were identified from the various larval collecting areas selected in the Quetta area are shown in Table V. This table also shows the percentage of the total of each species identified from the different localities enumerated in the table.

Table V.

Area from which collections made	*A. superpictus.*		*A. culicifacies.*		*A stephensi*	
	Number identified	Percentage	Number identified	Percentage	Number identified.	Percentage
Hanna river area ..	1,067	34	256	17	76	6
Lora stream area ..	1,049	33	522	35	480	40
Springs, etc. ..	343	11	158	10	279	23
Kareze system ..	224	7	373	25	193	16
Artesian wells, etc	166	5	190	12	104	9
Miscellaneous ..	307	10	13	1	79	6
Total ..	3,156	100	1,512	100	1,211	100

* Towards the end of the survey when the weather became very cold, the mortality among the larvæ was appreciably increased. The practice of collecting full-grown larvæ and pupæ may be open to the criticism that the sample taken was a selective one. It is thought that this defect is compensated for by the very large numbers of larvæ and pupæ collected during the survey.

Breeding of *A. superpictus* was most prevalent in connection with the Hanna and Lora areas. *A. culicifacies* breeding was also associated with these two areas, and with the kareze system, being found especially in irrigation channels, and in impounded waters connected with them. *A. stephensi* breeding-places were largely restricted to the vicinity of the Lora stream, and to the numerous springs and seepages lying between this stream and the railway.

(i) The Hanna river and irrigation channels arising from it.

The breeding-places in the Hanna area have been classified as below (*vide* Table VI):—

(*a*) Main streams of the Hanna river (current usually swift).
(*b*) Marshy areas in the river bed (current slow).
(*c*) Pools and ponds in the river bed (no perceptible current).
(*d*) Irrigation channels (current usually swift).

TABLE VI.

Classification of breeding-places.	*A. superpictus.*		*A. culicifacies.*		*A. stephensi.*	
	Number identified.	Percentage	Number identified	Percentage.	Number identified.	Percentage.
Main streams ..	321	30	54	21	6	8
Marshy areas in river bed.	543	51	107	42	51	67
Pools and ponds in river bed.	103	10	26	10	10	13
Irrigation channels ..	100	9	69	27	9	12
TOTAL ..	1,067	100	256	100	76	100

(*a*) *Main streams in the river bed.*—The bed of the Hanna river is stony, and, for the most part, devoid of trees, bushes, tall grass or other gross vertical vegetation. Throughout most of its course through the Hanna valley the river is not confined to a single main channel, but runs in several small streams which join each other at intervals only to separate off again into smaller channels (*vide* Plate III, fig. 1). The rate of flow in individual streams varies from place to place, but, as a rule, the central velocity is fairly high (sometimes as much as 2 miles an hour or more). The average fall in the river bed is about 100 feet per mile. During the period of the survey the total volume of water in the river remained fairly constant, since, owing to the absence of rainfall in the catchment area, no heavy spates occurred. Although the rate of flow in the centre of the main streams was fairly rapid, the current at the edges was much slower, and dense masses of Spirogyra were commonly found extending a foot or more from the shallow, shelving edges into the stream. Anopheline breeding was invariably intense wherever this mass of green algal growth was present; very few were recovered from the faster flowing water unless the mass of Spirogyra at the edges had previously been disturbed. *A. superpictus* was by far the most prevalent of the three common species in breeding-places of this type (*vide* Table VI).

(*b*) *Backwaters and marshy areas in the river bed.*—In addition to that occurring at the edges of the main streams, intense anopheline breeding was observed in various backwaters and marshy areas in the river bed. As in the case of the main streams the beds and edges of these places were stony, and the water contained dense masses of Spirogyra, but was innocent of gross vertical vegetation. The flow of water was definitely slower than was the case at the edges of the main streams, but, though sluggish, the motion of the water was definitely perceptible.

In breeding-places of this type, although *A. superpictus* was the most prevalent species, conditions were apparently more favourable for both *A. culicifacies* and *A. stephensi* than any other type of breeding-place found in the Hanna area (*vide* Table VI).

(*c*) *Pools and ponds in the river bed.*—In many places pools were encountered in the river bed in which no current was perceptible, but the water in them was constantly being changed as evidenced by an inflow and outflow of water. As before, the edges and beds of these pools were mostly stony, and the water was commonly a foot or more in depth. The most characteristic features of these pools and ponds were the absence of perceptible current, the presence of plentiful Spirogyra, the absence or scarcity of gross vertical vegetation, the exposure to direct sunlight, and the relatively deep water.

Breeding-places of this type were definitely less favoured than those in which the flow of water was perceptible. *A. superpictus* was again the most prevalent species, but the total number of this species collected from this type of breeding-place was but a small proportion of the total for this species in the Hanna area. *A. culicifacies* and *A. stephensi* were recovered in only small numbers from breeding-places in this category (*vide* Table VI).

(*d*) *Irrigation channels arising from the Hanna river.*—Collections of larvæ and pupæ made from all irrigation channels arising from the Hanna river have been included in this category irrespective of whether their eventual courses remained inside the Hanna valley.

The rate of flow in many of these irrigation channels was similar to that observed in the main streams of the Hanna river, but, in contrast to the latter, the irrigation channels were frequently heavily overgrown with grass and weeds. Vegetation of the algal type was, on the other hand, much less abundant than in the main streams in the river bed. On account of the greater amount of gross vertical vegetation, the more confined nature of the channels, and their steeper banks, the water in these irrigation channels is usually deeper and more shaded than the streams in the river bed. Anopheline breeding was observed chiefly in bays and pools along the edges of these channels, or in other situations where the current was relatively slow.

A. superpictus was again found to be the most prevalent species in breeding-places of this type, but the relative preponderance of this over the other carrier species was much reduced (*vide* Table VI).

(*e*) *Summary of the observations on anopheline breeding in the Hanna area.* —In every type of breeding-place investigated in the Hanna valley, *A. superpictus* was found to be the most prevalent species of *Anopheles* (*vide* Table VI). This species, however, showed a distinct preference for breeding-places in which the water was flowing relatively slowly but perceptibly, algal vegetation was abundant, gross vertical vegetation scanty or absent, and in which the water

was relatively shallow and exposed to direct sunlight [(*a*) and (*b*) above]. From such places 81 per cent of all the *superpictus* identified in the Hanna area were recovered.

A. culicifacies showed a distinct preference for water which was in perceptible motion (90 per cent), being found in approximately equal numbers at the edges of rapidly flowing streams and irrigation channels (48 per cent), and in more sluggishly flowing water (42 per cent).

A. stephensi was the least prevalent of the three malaria-carrying species in this area. This species showed a preference for slowly moving or still water (80 per cent), but was also found breeding in small numbers along the edges of rapidly flowing streams and irrigation channels.

(*ii*) *The Lora stream and its immediate vicinity.*

The Lora stream differs in several important respects from the Hanna river. Whereas in the latter the river flows in a number of small streams over a bare stony bed, the Lora is confined mainly to a single channel which flows in a depression which lies between high banks (*vide* Plate IV, figs. 3 and 4). The river bed is not stony and bare, but is rich in gross vertical vegetation such as grass, weeds, rushes, etc. Numerous seepages ooze out of the steep banks, and marshy areas along the banks are common, while a number of small side streams join the main stream at intervals.

It will be observed from the figures given in Table VII that the conditions for breeding were relatively more favourable for *A. superpictus,* than for *A. culicifacies* and *A. stephensi* which occurred in smaller and approximately equal numbers. Both the latter species were relatively more prevalent in the vicinity of the Lora stream than in the Hanna valley.

The breeding-places in the vicinity of the Lora stream have been subdivided as under (*vide* Table VII) :--

(*a*) The main Lora stream.
(*b*) Marshy areas in or near the main river bed.
(*c*) Pools, ponds, tanks, and other collections of still water in or near the river bed.
(*d*) Irrigation channel arising from the Lora stream.
(*e*) Small tributary streams.

(*a*) *The main Lora stream.*—The volume of water and the velocity of flow of the main Lora stream remained fairly constant throughout the whole period of the survey, and owing to the complete absence of rainfall in the locality, no spates occurred. The rate of flow of the water in the main stream varies somewhat from place to place, but on the whole the current was distinctly less rapid than in the case of the Hanna river. Unlike the latter the Lora is confined mainly to a single channel the edges of which are, for the most part, steeper than the shallow, shelving edges of the streams in the Hanna valley.

Anopheline breeding was often intense in the main stream itself especially in those parts where the current was sluggish, and vegetation, both algal and grassy, plentiful. In other parts where the bank was steep and devoid of vegetation larvæ were scanty or absent. It is probable that in such places the number of larvæ are kept down by the small fish which abound in the stream, and by other natural enemies.

TABLE VII.

Classification of breeding-places.	*A. superpictus.*		*A. culicifacies.*		*A. stephensi.*	
	Number identified	Percentage.	Number identified	Percentage.	Number identified	Percentage.
Main streams ..	357	34	23	4	96	21
Marshy areas and seepages in or near the river bed.	331	32	46	9	213	44
Pools, ponds, etc., in or near the river bed.	82	8	281	54	42	9
Irrigation channels ..	55	5	93	18	40	8
Small tributary streams	224	21	79	15	89	18
TOTAL ..	1,049	100	522	100	480	100

The actual numbers of each of the three important malaria-carrying species identified from the collections made in the main stream of the Lora are given in Table VII.

A. superpictus was found to be by far the most prevalent species, but both *A. culicifacies* and *A. stephensi* were also present, the latter being absolutely and relatively more prevalent than the former.

(*b*) *Marshy areas in or near the main river bed.*—Breeding-places of this type in the Lora neighbourhood resembled similar places in the Hanna valley, but differed from the latter in having earth instead of stony margins and beds, and in the presence of grass, weeds, etc , which however were not sufficiently dense to exclude direct sunlight from the surface of the water. In these places the flow of the water was sluggish but perceptible, the marshy areas representing accumulations of water issuing as seepages from the steep banks rising from the river bed of the main stream or its tributaries. All three of the carrier species were encountered in breeding-places included in this category. The actual numbers of each species identified are shown in Table VII.

Although *A. superpictus* was again the most prevalent of the three carrier species in breeding-places of this type, the most interesting observation was the high percentage of *A. stephensi* in such places, as compared with the other breeding-places associated with the Lora stream. This observation is in close agreement with the findings in the Hanna area where 67 per cent of all the *stephensi* identified were recovered from marshy areas in which the flow of water was sluggish.

(*c*) *Pools, ponds, tanks, etc., in or near the river bed.*—Included in this category are a number of pools, ponds, storage tanks, etc., in which there was no perceptible flow of water, but in which there was evidence of a constant inflow and outflow of water. Breeding-places of this type were invariably associated with grassy vegetation especially at the edges where most of the breeding was observed. This grassy vegetation was, however, never sufficiently dense to exclude direct sunlight from the water surface. The water was often a foot or more deep, and algal vegetation was usually abundant. The actual

number of each of the three carrier species identified from breeding-places of this type are given in Table VII.

Breeding-places of this type are particularly favoured by *A. culicifacies*, while both *A. stephensi* and *A. superpictus* are relatively and absolutely much less prevalent.

(*d*) *Irrigation channel arising from the Lora stream.*—Collections of larvæ and pupæ were made regularly from an irrigation channel arising from the Lora stream and flowing swiftly in a channel excavated from the steep bank rising from the bed of the main stream. Grassy vegetation was present along the edges of this channel but was not very abundant, and anopheline breeding was observed in bays along the edges. The actual number of identifications made from the collections in this channel are given in Table VII.

A. culicifacies was absolutely and relatively the most prevalent species in this channel, but both *A. superpictus* and *A. stephensi* were also recovered from it. The numbers of the two latter species were, however, small in comparison with those found in other places.

(*e*) *Small tributary streams of the Lora.*—At intervals along the Lora stream, small tributaries join the main stream. Some of these represent collections of the seepage outcrops which are so abundant along the steep banks of the Lora. The small tributaries frequently run in deep clefts which cut into the high banks of the Lora, at right angles to the main stream. As a rule the volume of water in the tributaries is small and the velocity of flow is very variable, though seldom rapid. Anopheline breeding was most intense in those parts where the current was relatively slow and where algal vegetation was most abundant. Little or no grassy vegetation was associated with these small streams. The actual numbers of each of the three carrier species identified from larvæ collected in breeding-places of this type are shown in Table VII.

As in other similar places in the Quetta area, *A. superpictus* was again the most prevalent species present, though both *A. culicifacies* and *A. stephensi* were also present in considerable numbers. The latter species again showed its liking for shallow, gently flowing water.

(*f*) *Summary of the observations on anopheline breeding in the Lora area.*—Although, as in the Hanna area, *A. superpictus* was by far the most prevalent of the three malaria-carrying species encountered in the Lora area, both *A. culicifacies* and *A. stephensi* were absolutely and relatively more prevalent here than in the Hanna area.

A. superpictus showed a definite preference for flowing water, particularly that in which the current was relatively slow. From such places 87 per cent of all larvæ and pupæ of this species were recovered. This finding is in close agreement with the observations made on this species in the Hanna area, though in the latter grassy vegetation was usually absent from breeding-places of this type. The presence of a considerable amount of grassy vegetation in the Lora area did not appear to inhibit the breeding of *A. superpictus*, but it was never sufficiently dense to afford more than partial shade from the direct rays of the sun.

A. culicifacies showed a distinct preference for breeding-places in which the flow of water was imperceptible, and in which there was generally a fair amount of grassy vegetation, particularly at the margins where breeding was most

intense. From such places 54 per cent of all the *culicifacies* identified from the Lora area were recovered. This species was also relatively prevalent in the irrigation channel (17 per cent), and in the small tributary streams (15 per cent), but was inconspicuous in the main Lora stream (4 per cent), and in the shallow marshy areas in which the current was sluggish (9 per cent).

A. stephensi showed a distinct preference for the shallow marshy areas in which the current was sluggish (44 per cent), and for those parts of the main and side streams in which the flow of the water was slow (38 per cent). This species was also found, in small numbers, in the other types of breeding-places investigated. The findings here in relation to this species are very similar to those in the Hanna area, though in the latter area the actual numbers of *A. stephensi* were much smaller than in the vicinity of the Lora.

(*iii*) *Springs and watercourses arising from them.*

Very numerous springs are present in close proximity to Quetta, particularly in the area lying between the railway line and the Lora stream. During the period of the survey elaborate anti-larval measures were being carried out in this area by the local health authorities. Fortunately we were able to make several collections of larvæ from various springs and their effluents before these control measures reached their ultimate degree of efficiency. Before the anti-larval measures were instituted anopheline breeding of almost incredible intensity was observed in connection with many of these springs. There is no doubt that the control measures employed interfered greatly with the results obtained during the survey, and in attempting to analyse the results of the collections made in breeding-places in this category, it must be emphasised that the actual numbers of identifications made are very much smaller than might otherwise have been the case. The *relative* prevalence of the different species in breeding-places connected with springs is, however, probably as reliable an index here as elsewhere.

It will be observed from the figures given in Table VIII that *A. superpictus* was the most prevalent species found breeding in connection with water arising from springs. *A. stephensi* was almost as prevalent, while *A. culicifacies* was much less prevalent. Relatively speaking, *A. stephensi* was more prevalent in the breeding-places of this category than in any others, and it seems probable that, but for the control measures employed, the largest numbers of *A. stephensi* would have been recovered from breeding-places associated with springs.

The breeding-places in this category have been subdivided as follows :—

(*a*) The Baleli spring.
(*b*) 'Five Springs'.
(*c*) Tarkha springs ('Four Springs').
(*d*) Forest Spinney.
(*e*) Impounded waters fed from springs.
(*f*) Irrigation channels arising from springs.

(*a*) *The Baleli spring.*—The Baleli spring is situated about midway between the Quetta Race Course and the Lora stream, and derives its name from the fact that the channel arising from it carries the effluent for some fourteen miles to supply domestic and irrigation water for Baleli. The spring itself occupies an area of over an acre, and lies in the pit of a large depression. At some parts the water is still and deep and completely devoid of all but algal

TABLE VIII.

Classification of breeding-places.*	*A. superpictus.*		*A. culicifacies.*		*A. stephensi.*	
	Number identified.	Percentage	Number identified.	Percentage	Number identified.	Percentage.
Baleli spring ..	47	14	21	13	63	23
'Five Springs' ..	79	23	1	1	146	52
Tarkha springs ..	56	16	26	16	19	7
Forest Spinney ..	2	1	17	11	11	4
Impounded spring water	18	5	79	50	20	7
Irrigation channels ..	141	41	14	9	20	7
TOTAL ..	343	100	158	100	279	100

* The comparatively small number of larvæ recovered from the breeding-places in this category is attributable largely to the anti-larval measures in operation during the survey.

vegetation, while in other parts the water is shallow, and contains some grassy vegetation. In the shallow parts of the spring, the water may be seen to be flowing gently over the semi-submerged spongy earth, while here and there perceptible currents may be observed in some of the deep fissures which are commonly seen traversing the shallower parts. The spring as a whole is fully exposed to the direct rays of the sun, and such grassy vegetation as is present is insufficient to afford any appreciable degree of shade. When visited at the beginning of August anopheline breeding was very intense in this spring, but later it was partially, and finally completely controlled by anti-larval measures. The numbers of each of the three carrier species identified from larvæ collected from this large spring are shown in Table VIII.

A. stephensi was relatively and absolutely the most prevalent of the three chief malaria-carrying anophelines.

(*b*) '*Five Springs*'.—The area known locally as 'Five Springs' lies approximately midway between the Baleli spring and the railway line. The name is rather misleading as the number of points at which water appears at the surface of the ground is greatly in excess of five. Unlike the Baleli spring and other springs to be mentioned below, those in the 'Five Springs' area make their appearance on relatively high ground so that the effluent trickles gently down the surrounding slopes and gives rise to shallow, grass-grown, marshy areas similar to those described in the vicinity of the Lora stream. No deep collections of water occur at the points of outcrop, but artificial reservoirs, situated at some distance from the outcrops, are fed by the effluent. In the marshy areas described above algal vegetation is plentiful, but grass and weeds, although present, do not grow to any appreciable height. The whole area is devoid of any vegetation which would tend to exclude the direct rays of the sun. The actual numbers of the three carrier species identified from collections made in this area are given in Table VIII.

The relatively small numbers of anophelines collected from the 'Five Springs' area is due to the fact that control measures were instituted relatively

early. It is clear, however, that *A. stephensi* was relatively and absolutely the most prevalent species found in this area, while *A. culicifacies* was extremely scarce. As in the case of the Hanna and the Lora areas, *A. stephensi* again showed a distinct preference for marshy areas with a sluggish current.

(*c*) *Tarkha springs* (*'Four Springs'*).—The Tarkha springs are situated near the village of the same name, and lie approximately midway between the Baleli spring and the Lora stream. These four springs arise in depressions in the ground, and grassy vegetation is present especially at the edges. The water is in very slow motion, and, compared with the marshy areas of 'Five Springs', the water is relatively deep.

The actual numbers of each of the three carrier species identified from these springs are given in Table VIII.

The numbers identified are too small from which to make any statements other than that all three species were encountered in these springs.

(*d*) *Forest Spinney*.—The area known locally as Forest Spinney is a forest nursery occupying a crater-like depression immediately to the south of the Quetta Race Course. Numerous springs appear on the surface of the ground in the bed of this depression, and vary in size from small marshy outcrops to extensive morasses, or definite 'pots' some twenty yards or more in diameter. In the latter the water is relatively deep, and apparently stationary, except for the 'boiling' appearance in their beds. The whole base of the large depression is more or less marshy and can be felt to shake when walking over it. Between the various springs, small connecting channels have been cut which serve to collect the effluent from the various outcrops, and eventually deliver it into one main irrigation channel. A very considerable degree of shade is afforded to the water surface of the various springs by the trees and shrubs which are cultivated in the Spinney. When visited at the end of July, anopheline breeding was prevalent throughout the Spinney, but this was quickly brought under control, and thereafter larvæ were seldom recovered. The information obtained with regard to the relative prevalence of the different species in this locality was, therefore, very limited, and the figures obtained (*vide* Table VIII) are too small to analyse. All three of the carrier species were found breeding in the Spinney, *A. culicifacies* being the one of which most larvæ were recovered while *A. superpictus* yielded the smallest number. There can be little doubt that, when uncontrolled, Forest Spinney is an extremely dangerous breeding-ground, and one which, on account of its very close proximity to the built-up areas of Quetta, must have an important influence on the incidence of malaria in the adjacent habitations.

(*e*) *Ponds and reservoirs used for impounding spring water*.—As in the case of irrigation water arising from other sources, it is a common practice in the Quetta area to construct open earth ponds and reservoirs for the storage of spring water. In some of the places of this nature grassy vegetation was scarce except at the edges, while in others the water surface was partially shaded by an abundant growth of grass, weeds, etc. The water in places of this kind is usually relatively deep, and no current is perceptible though the continuous, or almost continuous, passage of water through the ponds or reservoirs keeps the water fresh.

The figures given in Table VIII indicate that, as in similar breeding-places in connection with other irrigation supplies in Quetta, *A. culicifacies* showed a distinct preference for breeding-places of this type. This species was by far the

most prevalent of the three carrier species recovered from these impounded spring waters, though *A. superpictus* and *A. stephensi* were also present in small numbers.

(*f*) *Irrigation channels originating from springs.*—The effluent from springs is collected into, and carried away in, open earth ('kutcha') channels similar to those employed for irrigation purposes in connection with kareze, well, and river water (*vide* Plate VI, fig. 7). Irrigation channels arising from springs usually have deep vertical margins, which are heavily overgrown with grassy vegetation. In the channel itself water weeds and algal vegetation are usually abundant. Frequently these channels have a tortuous course, a mode of construction which is apparently designed to reduce the velocity of the outflow from the springs. In consequence of this irregular course bays and backwaters in which the current is greatly retarded are commoner than in the less tortuous channels arising from karezes and rivers. Anopheline breeding occurs chiefly in the more open places, in which the flow of the water is relatively slow.

The numbers of each of the chief carrier species identified from breeding-places of this type are given in Table VIII.

A. superpictus was the most prevalent species in breeding-places of this type, while, in contrast to the findings in irrigation channels arising from other sources, *A. culicifacies* was relatively uncommon. *A. stephensi* was also scarce. It is possible that the relatively slower current in the irrigation channels arising from springs may be more suitable for *A. superpictus* than the swifter current in those from other sources.

(*g*) *Summary of the observations made on anopheline breeding in connection with springs.*—The control measures adopted in that part of the Quetta area which is richest in springs undoubtedly had a great effect in reducing the amount of anopheline breeding, and but for this it is possible that a larger number of larvæ would have been collected from spring water than from most other types of breeding-places.

As in the other places investigated *A. superpictus* was encountered in greatest abundance in flowing water, particularly in those places where the current was relatively sluggish. From such places 78 per cent of all the specimens of this species found breeding in connection with springs and their effluents were recovered.

A. culicifacies was relatively inconspicuous in breeding-places associated with springs, but, as in the breeding-places included in most other categories, this species was abundant in collections of water in which the flow of water was imperceptible and in which grassy vegetation was relatively plentiful. In such places 50 per cent of all specimens of this species found breeding in association with spring water were recovered. The remainder were found in small numbers in the various other types of breeding-places connected with springs.

A. stephensi was relatively more prevalent in breeding-places connected with springs, than in those of any other category investigated. This species again demonstrated its marked preference for breeding-places of the marshy type in which the water was shallow and flowing sluggishly. In such places 75 per cent of the specimens of this species were recovered.

(*iv*) *The kareze system.*

A description of the kareze system has already been given (*vide* p. 309). Owing to the prevalence of karezes in the Quetta area special attention was

directed to the possible influence of this somewhat peculiar system of irrigation on the malaria problem.

The numbers of each of the three important malaria-carrying anophelines which were identified from collections of larvæ and pupæ made from the kareze system are given in Table IX. The conditions for breeding were relatively more favourable for *A. culicifacies* than for either *A. superpictus* or *A. stephensi* which were recovered in smaller and approximately equal numbers.

For convenience of description it is necessary to consider the findings relating to anopheline breeding in karezes according to the portion of the karezes from which the collections were made, and for this reason the following subdivisions have been adopted :—

(*a*) Underground kareze channels exposed only by deep shafts at relatively infrequent intervals (15 to 20 yards or more apart).

(*b*) Kareze channels which are partially underground and partially open to direct sunlight.

(*c*) Open irrigation channels conveying kareze water.

As will be shown below the amount of anopheline breeding which takes place in different parts of a kareze channel varies enormously according as to whether the channel is open or mostly underground (*vide* Table IX).

TABLE IX.

Classification of breeding-places.	*A. superpictus.*		*A. culicifacies.*		*A. stephensi.*	
	Number identified	Percentage.	Number identified.	Percentage	Number identified.	Percentage.
Underground kareze channels.*	..	..	5	1	10	5
Partially exposed kareze channels.	68	30	142	38	114	59
Open kareze channels ..	156	70	226	61	69	36
TOTAL ..	224	100	373	100	193	100

* Special attention was given to the collection of larvæ from underground kareze channels.

(*a*) *Kareze channels which are mostly underground.*—In spite of careful and repeated searches, no anopheline larvæ were ever recovered from deep underground kareze channels where the kareze shafts were 20 yards or more apart. In such places light is excluded to such an extent as to prevent the growth of green vegetation. Larvæ of *A. stephensi* and *A. culicifacies* have, however, been recovered in very small numbers (*vide* Table IX) from those parts of kareze channels where the depth of the kareze shafts does not exceed 25 feet, and where the shafts are about 15 yards or less apart. The finding of anopheline larvæ in such places is *quite exceptional* and usually only occurs where bays are formed on the edges of the channel as the result of an alteration in the direction of flow.

(*b*) *Kareze channels which are partly underground and partly exposed to direct sunlight.*—It frequently happens that a kareze channel is intermediate in nature between the underground channels described above, and the open channels to be described below. In such parts of their courses the channels themselves are alternately open to direct sunlight and underground (*vide* Plate V, fig. 5). A common cause for this state of affairs is the falling in of the roof and sides of the tunnels for a length of 20 or 30 yards or more. In such situation the amount of sunlight is generally sufficient to allow of the growth of green vegetation. Anopheline breeding has frequently been observed in these open spaces, but it cannot be said that it is, as a rule, as intense as in the open channels to be described below.

The actual numbers of the three carrier species identified from the collections of larvæ and pupæ made in breeding-places of this type are given in Table IX. Although the number of *A. culicifacies* recovered from breeding-places of this type was greater than for either of the other two species, such places were relatively more suitable for *A. stephensi* than the other parts of the kareze system.

In many of the breeding-places of this type the flow of water in the kareze channels was relatively slow owing to the occurrence of pools, the formation of which is facilitated by the falling in of earth from the roof and sides of the former tunnel. The amount of vegetation present is somewhat variable, but is usually scarce. A little grass or a few tall reeds may be seen, and Spirogyra is sometimes fairly plentiful.

(*c*) *Open irrigation channels arising from karezes.*—In the terminal parts of their courses kareze channels come to the surface and are subsequently similar to open earth ('kutcha') irrigation channels arising from other sources. They are, however, less tortuous and contain less water-weed than some of those arising from springs. At first the open kareze channels may be confined within steep precipitous banks which, in addition to the profuse grassy vegetation which grows on the edges of the channels, afford some degree of shade from the direct rays of the sun. Later, however, kareze channels present no essential differences from other irrigation channels.

Anopheline breeding in open kareze channels, as in other irrigation channels, is very considerable. The actual numbers of each of the chief malaria-carrying species identified from larvæ and pupæ recovered from breeding-places of this type are shown in Table IX.

A. culicifacies was the most prevalent species in the open kareze channels as it was in irrigation channels of other types (except those arising from springs).

A. superpictus, though less prevalent than *A. culicifacies* in breeding-places of this type, was relatively more prevalent than in the partially underground parts of kareze channels. On the other hand *A. stephensi* was more prevalent in breeding-places of the latter type than in the open channels.

(*d*) *Summary of observations on anopheline breeding in connection with the kareze system.*—Certain parts of the courses of kareze channels are important breeding-places for anopheline mosquitoes. In the upper portions of their courses where the water flows in dark underground channels exposed to the light only through deep shafts spaced at relatively long intervals, there is no evidence that any appreciable amount of anopheline breeding occurs. This conclusion has been reached after a very exhaustive investigation. Anopheline

breeding is most marked in the open irrigation channels arising from karezes and which do not differ materially from irrigation channels in the Quetta area arising from other sources. A condition intermediate between these two conditions is observed where the kareze tunnel has fallen in or where the shafts are so wide or so close together that a sufficient degree of sunlight is admitted to allow of the growth of green vegetation. In situations of the latter type, *A. culicifacies* and *A. stephensi* are the most prevalent species of *Anopheles* found.

(*v*) *Artesian and tube wells, and watercourses arising from them.*

In the vicinity of Quetta there are a considerable number of artesian and tube wells, the water from which is used for irrigation purposes. These wells are more numerous in the neighbourhood of Galbraith Spinney, which lies to the south of Quetta. The anopheline breeding-places which are associated with this system of irrigation include the wells themselves; the irrigation channels arising from them; pools, ponds and seepages connected with the latter; and open earth reservoirs used for storing irrigation and domestic water.

The breeding-places in this category may be subdivided into two groups according as to whether the water was still or flowing (*vide* Table X).

(*a*) Wells, storage reservoirs, and ponds and pools arising from leaks and overflows.

(*b*) Irrigation channels.

TABLE X.

Classification of breeding-places.	*A. superpictus.*		*A. culicifacies.*		*A. stephensi.*	
	Number identified.	Percentage	Number identified.	Percentage.	Number identified.	Percentage
Wells, storage tanks, pools, ponds, etc.	39	24	56	29	66	64
Irrigation channels ..	127	76	134	71	38	36
TOTAL ..	166	100	190	100	104	100

(*a*) *Wells, storage reservoirs, etc.*—Anopheline breeding was seldom observed in the wells themselves. One open well was visited on numerous occasions and, although culicine larvæ were present at every visit, anopheline larvæ were found on only one occasion. So long as the level of the water in this well remained about four feet or more below the surface, no anopheline breeding was observed. When, however, the water in this well rose to ground level the water was fully exposed to the direct rays of the sun, and extensive anopheline breeding was observed.

The storage reservoirs, and the pools and ponds originating from leaks and overflows from the effluent of the wells showed no essential differences from those described in connection with other irrigation systems. Grass and weeds were usually plentiful, especially near the edges, but the vegetation was never

sufficiently dense to afford more than partial shade from the direct rays of the sun. No perceptible movement of the water could be detected though it was known that in all cases the water was kept fresh by a continuous inflow and outflow.

The numbers of each of the carrier species identified from the breeding-places included in this category are shown in Table X. These figures are too small from which to make any deductions, but it would appear that the breeding conditions in places of the type under consideration were relatively more favourable for *A. stephensi* than in the irrigation channels to be considered below.

(*b*) *Irrigation channels arising from artesian and tube wells.*—These channels were similar in most respects to those arising from rivers, karezes and springs, though they differed somewhat from the latter in being less tortuous. With the exception of those which were partially shaded by the trees in Galbraith Spinney, the remainder were unshaded. As a rule they were much overgrown with grass and weeds, and the flow of water was sometimes less swift than in some of the irrigation channels of other types.

The actual numbers of each of the three important carrier species identified from larvæ and pupæ and collected from these irrigation channels are shown in Table X.

A. culicifacies was, as in irrigation channels of most other types, the most prevalent species. *A. superpictus* was almost as prevalent as *A. culicifacies.* It is probable that the relatively slower current in the irrigation channels arising from wells may have been more suitable for *A. superpictus* which, as has been shown, was the most prevalent of the carrier species in the relatively slow-flowing, tortuous channels arising from springs.

(*c*) *Summary of observations on anopheline breeding in connection with wells and irrigation channels arising from them.*—Except, perhaps, in some of the pools resulting from leakages and overflows, the amount of anopheline breeding in connection with artesian and tube wells and their effluents was less intense than in many other places investigated. The numbers of each species identified are insufficient on which to base any definite statements regarding the preferential breeding-places of the different species. All three of the chief malaria-carrying species were present in approximately equal numbers, the most prevalent species being *A. culicifacies.* The proportion of the latter species to the total number of this species collected from all sources during the survey was higher than in the case of the other two species.

(*vi*) *Miscellaneous breeding-places.*

In addition to the breeding-places already considered, collections of larvæ were also made from a variety of miscellaneous breeding-places. Of these the most intense breeding-places were found to include subsoil water lying in cracks and fissures in the ground, and marshy areas (seepages) unconnected with any of the various categories already considered.

In addition to the breeding-places mentioned above regular visits were made to a variety of other potential breeding-places of a miscellaneous character. These included covered springs, cisterns, concrete siphon pits, concrete storage tanks, cooling tanks, etc. In spite of repeated visits and careful

searches, no anopheline larvæ were recovered from any of these places. This was a matter of some surprise as it is well known that *A. stephensi* may breed in large numbers in places of this kind in other localities.

(*vii*) *General classification of the breeding-places of the three chief malaria-carrying anophelines of Quetta.*

An attempt has been made to classify the chief breeding-places of the three important malaria-carrying anophelines of the Quetta area into five main groups, and to show the relative prevalence of each of the three species in these groups. The results are shown in Table XII, which is self-explanatory.

TABLE XII.

Classification of breeding-places.	*A. superpictus.*		*A. culicifacies.*		*A. stephensi.*	
	Number collected.	Percentage.	Number collected.	Percentage.	Number collected.	Percentage.
Rivers and streams. Flowing water; direct sunlight; Spirogyra very plentiful, etc.	1,586	50	217	14	211	17
Seepages and marshy areas. Very sluggish current; direct sunlight; Spirogyra plentiful; grassy vegetation present.	614	19	117	8	460	38
Springs, ponds, pools, etc. No perceptible current; direct sunlight; usually grassy vegetation present; relatively deep water.	448	14	492	33	249	21
Open irrigation channels. From springs, rivers, wells, karezes, etc. Flowing water; grassy vegetation; direct sunlight.	438	14	522	35	156	13
Shaded places. Wells, underground karezes, under trees, etc. Little or no grassy vegetation.	70	3	164	10	135	11

(*viii*) *The association of different species of* Anopheles *in various breeding-places in the Quetta area.*

Analysis of 167 collections of larvæ and pupæ recovered from various breeding-places in the Quetta area shows that, with a single exception, one or more of the three important malaria-carrying anophelines was found breeding in all these places. The following statement shows the number of collections made in which all three or fewer of the carrier species were encountered :—

Number of collections in which 3 carrier species present	..	77
Number of collections in which 2 carrier species present	..	60
Number of collections in which only 1 carrier species present	..	29
Number of collections in which no carrier species present	..	1
Total number of collections	..	167

It is clear from the above figures that, during the period of the survey, practically all places in which anopheline breeding was observed are potentially dangerous ones. From the practical point of view this means that wherever anopheline larvæ are found in the Quetta area during the malaria season, the breeding-places in which they occur must be regarded as dangerous ones. The opportunities, therefore, for applying the principle of 'species sanitation' in Quetta appear to be non-existent. There is here an answer to the popular question in Quetta as to how the high incidence of malaria may be explained in a locality where there is so little water. While it is true that the amount of water in the Quetta area appears to be small, there being no lakes, swamps, or extensive areas of 'wet' cultivation, the explanation lies in the fact that practically all water in this locality is highly dangerous.

Further analysis of the data collected from the examination of the 167 collections of larvæ from various breeding-places shows that as many as seven different species have been recovered from a single breeding-place. The finding of but a single species in any given breeding-place was a comparatively rare occurrence. A statement showing the different combinations of species of *Anopheles* in various breeding-places, and the number of occasions on which such combinations were observed, is given in Appendix II.

B CONSIDERATIONS IN REGARD TO INDIVIDUAL SPECIES OF *ANOPHELES* FOUND IN THE QUETTA AREA.

1. *A. SUPERPICTUS*

(*a*) Geographical distribution.

A. superpictus has a wide distribution throughout the sub-montane and mountainous tracts of the southern European countries, of Palestine, and of Upper Mesopotamia. In the Indian area the occurrence of this species has not been recorded east of the Indus. Its apparent restriction to the north-west of India represents the eastern limit of distribution of this Mediterranean species.

(*b*) Relative and seasonal prevalence in Quetta.

During the period of the survey of the Quetta area, *A. superpictus* was the most prevalent species of *Anopheles* present. Out of a total adult catch of

7,023 specimens of all species, 3,683 (53 per cent) were identified as *A. superpictus,* while of 7,049 bred specimens of all species, 3,156 (45 per cent) were found to be *A. superpictus.*

By 25th July, *A. superpictus* was already the most prevalent anopheline mosquito in the Quetta area, and except during the first two weeks of August, when *A. stephensi* was the most prevalent species, it remained so throughout the whole period of the survey. The relative preponderence of this over other species was most marked from the middle of September until the conclusion of the survey. No precise information is available with regard to the prevalence of *A. superpictus* prior to the commencement of the main survey. During the preliminary survey in May adult anophelines were extremely scarce. In this connection it may be remarked that the season was a particularly late one, and that exhaustive searches were not possible in the short time available.

According to Davys (1912), *A. superpictus* made its first appearance in Quetta at the end of May, and was the most prevalent species during June. In July, however, *A. culicifacies* became the most prevalent species and continued to be so until November. Gorman (1933), working in the cantonment area, found that *A. culicifacies* was the most prevalent species during May and June, and *A. superpictus* the most prevalent in July. In August these two species were present in approximately equal numbers, but in September and October *A. superpictus* was by far the most prevalent species in Quetta. The numbers on which these observations are based are, however, very small. The statements made by these two workers are somewhat conflicting, but they are apparently in agreement that both *superpictus* and *culicifacies* adults appear in appreciable numbers in June. The discrepancies in the reports of these authors may be due to the fact that they were working in different parts of the Quetta area, and to the small number of mosquitoes identified. Our observations show that, during the period of the survey, *superpictus* was always more prevalent than *culicifacies* in the Quetta area as a whole.

(*c*) Relation to the transmission of malaria.

Although *A. superpictus* has been proved to be a dangerous malaria-carrier in southern Europe, Palestine and Upper Mesopotamia, there are no previous records regarding the part played by this species in the transmission of malaria in any part of the Indian area where it is known to occur.

Cardamatis (1919) records that in Greece in 1903 and 1904 when there was very little malaria, only 0·16 per cent of wild-caught specimens of *A. superpictus* were found to be infected. During a malaria epidemic which occurred in 1905, the percentage of naturally infected specimens of this species rose to 10 per cent. The actual numbers dissected are not stated. Christophers and Shortt (1921) found that the presence of *A. superpictus* in Upper Mesopotamia was associated with a high spleen rate amongst the native communities, and a high incidence of malaria among the troops. Of 27 specimens dissected 4 were found to be infected (7·4 per cent). These authors quote Mackie as having informed them that, of 105 specimens of *A. superpictus* dissected in Mesopotamia, one gut and two gland infections were observed. As *A. superpictus* was the only species of *Anopheles* present in some places, they conclude that this was the responsible malaria carrier over most of northern Mesopotamia.

Cot and Hovasse (1917) record the dissection of 60 *A. superpictus* in Macedonia, of which 2 showed malarial infection (3·3 per cent). More

extensive investigations were carried out by the Malaria Unit attached to the British Expeditionary Force in Macedonia in 1917-18. This work is reported by Wenyon (1921) and contains much information about *A. superpictus*. A total of 2,831 specimens was dissected during this period, of which 25 were found to be infected (0·8 per cent). The highest seasonal infection rate found was 1·5 per cent among specimens captured between July and October 1918.

Kligler (1924) dissected 39 specimens of *A. superpictus* in Palestine out of which 1 was found to be infected (2·6 per cent). In a later publication Kligler (1930) states that in Palestine the percentage of *superpictus* found infected was 1·5 per cent, but the total number dissected is not stated.

In a recent paper, Barber and Rice (1935) discuss the rôle of *A. superpictus* in the transmission of malaria in Macedonia. They found that, in the laboratory, *A. superpictus* was more susceptible to malaria than either *A. elutus* or *A. maculipennis*. In nature, the sporozoite rate (1·48) was higher than in *A. elutus* in 1932, but it was lower than in *A. elutus* in the two subsequent years (0·52 and 0·45 in 1933 and 1934 respectively). From the data given by these authors it seems not unlikely that the part played in the spread of malaria by *A. superpictus*, which appears relatively late in the malaria season, is dependent to some extent on the creation of a population of gametocyte carriers through the activities of the other carrier species which appear earlier in the season.

Although, as has been shown above, *A. superpictus* is a proven malaria carrier in Europe, Palestine and Mesopotamia, it could not be assumed that it was a carrier of malaria in Baluchistan. Assumptions of this kind have been most misleading in the past. It was necessary, therefore, to investigate this problem afresh. A total of 1,412 specimens of *A. superpictus*, captured in nature, was dissected between 25th July and 9th October, 1935. Of these 69 (4 9 per cent) were found to be infected. Details of these dissections, by weekly periods, are given in Table XIII

TABLE XIII.

Showing results of dissections of 1,412 A. superpictus *by weekly periods.*

Week ending	Number dissected.	Number with gut only infected.	Number with gland only infected.	Number with gut and gland infected.	Total number infected.	Percentage infected.
31st July ..	71	0	0	0	0	0·0
7th August ..	76	1	2	1	4	5·3
14th „ ..	120	2	3	2	7	5·8
21st „ ..	186	6	1	4	11	5·9
28th „ ..	125	5	6	1	12	9·6
4th September ..	131	2	5	0	7	5·3
11th „ ..	189	10	2	1	13	6·9
18th „ ..	113	7	2	1	10	8·8
25th „ ..	97	2	1	1	4	4·1
2nd October ..	202	1	0	0	1	0·5
9th „ ..	102	0	0	0	0	0·0
TOTAL ..	1,412	36	22	11	69	4·9

It will be observed from Table XIII that a fairly high percentage of infection in *A. superpictus* was found to occur during the months of August and September. Unfortunately the survey was commenced too late to be sure that infections in this species were not also occurring in July, but such evidence as there is suggests that the prevalence of infected *A. superpictus* in the season under review, commenced to show an increase about the beginning of August. Towards the end of September the percentage of infected *superpictus* showed a very sudden and marked decline, and out of over 300 specimens dissected between 26th September and 9th October, only one was found to be infected (gut only). The latter observation is interesting in that the latter period is that in which this species begins to show certain changes which have been interpreted as being preparatory to hibernation. It is very improbable, therefore, that many infections are carried over the winter in hibernating mosquitoes of this species.

Another factor which might be expected to influence the infection rate in *A. superpictus* is the locality from which the dissected specimens were captured. The results of dissections of this species, classified according to the 'catching areas' from which adults were collected, are given in Table XIV.

TABLE XIV.

'Catching area'*.	Number dissected	Number infected.	Percentage infected.
Hudda village	347	15	4·3
Kotwal and Navagaon villages .	649	27	4·2
Railway and police lines ..	106	7	6·6
Military area	87	3	3·4
Civil Hospital	14	3	21·4
Karezes and hill caves ..	204	14	6·8

* Details of these catching areas are given in Table I.

It will be observed from these figures that the highest percentage of infection in *A. superpictus* was found to occur among the adults collected from the Civil Hospital. The numbers are very small and are therefore liable to be misleading. It is probable, however, that the aggregation of malaria patients in the hospital was responsible for this high figure. The lowest infection rate was observed in the military area although the collections were made from the most malarious part of the cantonment. The most striking observation was the high percentage of infection among *A. superpictus* collected from outdoor resting-places (karezes and caves). In such situations the infection rate was higher than in any other category with the exception of the Civil Hospital. This finding is somewhat surprising in as much as the karezes and caves investigated were often a quarter of a mile or more from the nearest human habitation. The possibility of the mosquitoes found in these outdoor resting-places having fed on wandering sheep- or goat-herds cannot be overlooked, but this seems unlikely. It is more probable that *A. superpictus* seeks out these resting-places after having visited some neighbouring village for the purpose of obtaining a blood meal. This observation requires confirmation and further study as it has obvious importance in relation to practical malaria control measures.

(*d*) THE DIURNAL RESTING-PLACES OF *A. superpictus.*

The diurnal resting-places of the Quetta anophelines have already been considered in general terms. In spite of the somewhat abnormal conditions under which the population of Quetta was living after the earthquake, anopheline mosquitoes were numerous, and among them *A. superpictus* was found to be the most prevalent species. The latter finding applied equally to the areas devastated by the earthquake and to those which were little or not at all affected by it. There is no evidence, therefore, that the predominance of *A. superpictus* was in any way attributable to the greater adaptability of this species to the abnormal conditions, prevailing after the earthquake. This is supported by the fact that the larvæ of this species were more prevalent than those of any other species.

Adults of *A. superpictus* were collected from a wide variety of resting-places, in which they were commonly associated with other species, particularly with *A. culicifacies* and *A. stephensi.* In certain types of resting-places *A. superpictus* was relatively more prevalent than in others, a finding which was explicable, in some instances, by the proximity of breeding-places which were more favourable for this than for other species. In some instances, however, particularly in outdoor resting-places (karezes, caves), *A. superpictus* adults were captured in relatively greater numbers than would have been expected considering that the nearby breeding-places were relatively more suitable for other species. The impression gained during the survey was that *A. superpictus* displayed a much greater tendency to seek out favourable outdoor resting-places than either *A. culicifacies* or *A. stephensi,* which appeared to be more dependent upon human habitations or other resting-places in their immediate vicinity.

It does not appear from our investigations that *A. superpictus* resorted to outdoor resting-places after emergence from the pupal stage in preference to visiting neighbouring human habitations for the purpose of obtaining a blood meal. On the contrary a high proportion of the females of this species captured in outdoor resting-places showed evidence of having ingested a blood meal, and a surprisingly high percentage of such females was found to be infected with malaria. There is, therefore, some evidence to support the belief that *A. superpictus* deliberately seeks out favourable outdoor resting-places to a greater extent than the other species investigated. This observation is of some practical importance because it is possible that this species resorts to those outdoor resting-places in which the temperature and humidity are particularly favourable for its survival. *A. superpictus*, by virtue of its ability to select suitable resting-places, may therefore be capable of surviving the relatively cool, dry, climate of Quetta better than either *A. culicifacies* or *A. stephensi* which are apparently more 'domestic' in their habits. It seems possible that, in years in which the general climatic conditions are less favourable for the longevity of mosquitoes than was found to be the case in the period under review, *A. superpictus* might have recourse to suitable micro-climates to an even greater degree. This species might, therefore, be capable of acting as a malaria-carrier in years when neither *A. culicifacies* nor *A. stephensi* would be able to survive sufficiently long to be of importance as carriers. If this be true, the danger of malaria transmission by *A. superpictus* might be dependent more upon the state of its breeding-places than upon the local conditions of temperature and humidity during the malaria season. With regard to the

favourite breeding-places of *A. superpictus,* the amount and distribution of rainfall (both local and distant) would be expected to exert a profound influence on the breeding of this species. Thus, in a year in which the rivers, springs, etc., were dry or nearly so, breeding of this species would be greatly restricted. On the other hand heavy falls of rain occurring periodically during the malaria season would tend to restrict *superpictus* breeding automatically by flushing out its favourite breeding-places. The effects of both drought and flushing would also be expected to reduce the breeding of the other two carrier species, though probably to a less extent than in the case of *A. superpictus.*

It was observed that, during the height of the malaria transmission season, *A. superpictus* adults were recovered in large numbers from outdoor resting-places such as karezes and caves. When, however, the weather became colder (late September) there was a sudden and marked reduction in the numbers of this species recovered from outdoor resting-places. The fall in the numbers of *A. superpictus* in outdoor resting-places was much more marked than was found to be the case in other situations such as human habitations and animal houses. About the same time as adult *superpictus* begin to disappear from outdoor resting-places, changes appear in the adult females which have been interpreted as being preparatory to hibernation (*vide* p. 307). The stimulus to forsake outdoor resting-places may be supplied by the necessity of finding suitable resting-places for the period of hibernation. The latter would appear to be the warmer environment of human and animal houses, in which there would also be easy access to blood meals. It seems probable from these considerations that *A. superpictus* is capable of adapting itself to the general climatic conditions of Quetta perhaps to a greater degree than any of the Indian or Oriental species.

(*e*) Dispersion of *A. superpictus.*

A. superpictus is a large sturdy mosquito and is probably, therefore, capable of a longer range of flight than either *A. culicifacies* or *A. stephensi.* According to Kligler (1930) this species may disperse up to distances of 3 5 kilometres or more. We are not so much concerned with how far this mosquito is capable of travelling as with the distances to which it will ordinarily disperse from its breeding-places during the season when malaria transmission is going on.

It was not possible, during the survey under discussion, to carry out any flight experiments, but so far as our observations go, no evidence was obtained that *A. superpictus* disperses to exceptionally long distances in Quetta. Wherever this species was encountered in large numbers suitable breeding-places were to be found in close proximity. Thus, in the Kotwal-Navagaon group of villages, 1,212 specimens of *A. superpictus* were collected as adults, and of these 484 (32 per cent) were males. Extensive breeding-grounds from which *superpictus* larvæ were repeatedly recovered, surround these villages, and sufficient were present within a quarter of a mile to explain the large number of adults present in the villages. Similarly in Hudda village where 596 adult *superpictus* were captured (19 per cent of which were males), suitable breeding-places were found within half a mile of these villages. In the military area also 202 *superpictus* adults were captured (42 per cent of which were males) from a catching area within a quarter of a mile from known breeding-places of *superpictus.* These examples serve to show that, in the instances quoted, it was

unnecessary to postulate a long range of flight to account for the presence of numerous adults in or near human habitations. The fact that a high percentage of males was present lends some support to the belief that the distances to which *superpictus* was dispersing were relatively short ones. On the other hand it was observed that where no suitable breeding-places for *A. superpictus* were present within a radius of about half a mile, or where such breeding-places were controlled, adults of this species were very scarce. A good example of this is shown by the adult catches made in Civil Lines. The latter area was carefully controlled during the greater part of the malaria season and adult mosquitoes were so scarce that regular catches were abandoned in this area. At least one extensive and uncontrolled breeding-ground for *superpictus* was present not more than half a mile from Civil Lines, but in spite of this, *A. superpictus*, and indeed all other species of anophelines, were conspicuous by their absence. This finding is incompatible with the belief that *superpictus* was dispersing to long distances, at least in this particular instance. Similar observations were made in other parts of the Quetta area.

While these observations do not disprove that *A. superpictus* may be capable of dispersing over long distances, they seem to indicate that under the conditions prevailing in the Quetta area during the malaria season, this species showed no tendency to disperse to distances much in excess of half a mile. This question is of particular interest with regard to the choice of healthy sites for the reconstruction and expansion of Quetta. Much probably depends, however, on the presence of suitable sources of food and shelter for this species, between breeding-places and the area which it is desired to protect. It must also be remembered that in years which prove to be exceptionally favourable for the breeding and longevity of this species, it might tend to infiltrate further into built-up areas, and cause exacerbations of malaria. Under such circumstances the use of insecticidal sprays might be expected to be of considerable benefit. The latter, however, would not have any effect upon the *superpictus* adults in outdoor shelters.

(*f*) Preferential breeding-places of *A. superpictus*.

A detailed analysis of the chief breeding-places of the three important malaria-carrying anophelines of Quetta has already been given (*vide* p. 314), and it is only necessary here to summarise these findings.

A. superpictus showed a marked preference for breeding in flowing water, and was found in greatest profusion along the edges of rivers and streams. Although the central velocity of these streams was sometimes high, the current at the edges was usually relatively slow being retarded somewhat by the dense masses of Spirogyra which were so commonly found in such situations. Larvæ were usually observed in large numbers when this dense mass of Spirogyra was broken up by hand or with the collecting net. Fifty per cent of all the *superpictus* larvæ collected in the Quetta area were recovered from breeding-places of this type.

In seepages and marshy areas in which there was a gentle flow of water, *A. superpictus* was also found breeding in profusion. As a rule green algal vegetation was plentiful in such places, and grassy vegetation, if present, was never sufficiently dense to afford any appreciable degree of shade. Nineteen per cent of the larvæ of *superpictus* collected in the Quetta area were recovered from breeding-places of this type.

Open irrigation channels arising from rivers, wells, karezes and springs, were also responsible for a certain amount of *superpictus* breeding. This was especially true of the tortuous channels conveying spring water in which the flow was relatively slow. Larvæ were found mostly in bays and backwaters along the edges. Grassy and algal vegetation was usually fairly abundant. Fourteen per cent of all the *superpictus* larvæ collected in the Quetta area were recovered from places of this type.

In addition to the places mentioned above, *A. superpictus* was also found breeding in reservoirs, pools, wells, springs, subsoil water in cracks and fissures in the ground, and other similar places in which there was no perceptible current of water. The amount of vegetation in these different breeding-places was variable, but in no case were the larvæ of this species found breeding where there was dense shade. Fourteen per cent of the total larval catch of *A. superpictus* in the Quetta area were recovered from breeding-places of this nature.

A small proportion (3 per cent) of the *superpictus* larvæ collected were recovered from breeding-places other than those of the different types referred to above. Among these may be mentioned partially underground karezes, partially shaded springs, etc.

The chief characteristics of the favourite breeding-places of *A. superpictus* appear to be :—

(*i*) Exposure to the direct rays of the sun.

(*ii*) Flowing water, particularly that with a gentle but perceptible current.

(*iii*) Plentiful aquatic vegetation, particularly that of the algal type.

A. superpictus has been found breeding in most of the types of breeding-places in the Quetta area from which other species of anophelines have been recovered. The larvæ of this species are very shy, and may remain submerged for long periods (15 minutes or more) when disturbed. If this characteristic be not fully realised, the presence of this species in any particular breeding-place may easily be overlooked. In marshy areas in river beds, particularly in those in which the water is very shallow, the presence of *A. superpictus* larvæ may be very difficult to detect. This is greatly facilitated by lifting stones and allowing the water, thus rendered muddy, to collect in small pools. At the edges of river beds the collection of larvæ of this species is greatly facilitated by breaking up the dense masses of Spirogyra which is usually abundant in such places. The collector should not be dissuaded from searching for larvæ by reason of a very rapid flow in the central part of a channel or stream.

2. *A. CULICIFACIES.*

(*a*) Geographical distribution.

A. culicifacies is essentially an Indian species, and has been recorded from outside the Indian area only from Siam, Tonkin and South Arabia. This species is distributed widely throughout India and Ceylon, and its occurrence in Quetta is probably close to its western limit of distribution.

(*b*) Relative and seasonal prevalence of *A. culicifacies* in Quetta.

Next to *A. superpictus*, *A. culicifacies* was found to be the most prevalent species of *Anopheles* in the Quetta area during the period of the survey. Out of a total adult catch of 7,023 specimens of all species, 1,606 were *A. culicifacies*

(23 per cent), while of 7,049 bred specimens of all species 1,512 (21 per cent) were identified as *A. culicifacies*. Only a few adults of this species were captured during the preliminary survey in May, but adults were prevalent when the main survey was commenced towards the end of July. It is not therefore possible to state exactly when this species becomes prevalent. According to Gorman (1933) *A. culicifacies* is the most prevalent species during May and June, while Davys (1912) states that *A. superpictus* is the most prevalent species during this period (*vide* p. 330). Our observations show that *A. culicifacies* was the second most prevalent species in Quetta during August and September but towards the end of the latter month the number of adults collected showed a rapid decline and by the first week in October adults of this species had almost disappeared.

(*c*) Relation to the transmission of malaria.

A. culicifacies is generally acknowledged to be the most dangerous malaria-carrying species in India except, perhaps, in the eastern areas (Assam, Bengal) where *A. minimus* is so important. There are numerous records of natural malarial infections in *A. culicifacies* from many parts of India and Ceylon, and the infection rate has frequently been observed to be in the neighbourhood of 5 per cent or over.

A total of 835 specimens of *A. culicifacies*, captured in nature in the Quetta area between 25th July and 9th October, 1935, was dissected. Of these 44 (5·1 per cent) were found to be infected. A detailed statement of these dissections, by weekly periods, is given in Table XV.

Table XV.

Showing results of dissections of 835 A. culicifacies *by weekly periods.*

Week ending	Number dissected	Number with gut only infected.	Number with gland only infected.	Number with gut and gland infected.	Total number infected.	Percentage infected.
31st July ..	37	1	0	0	1	2·7
7th August ..	73	3	1	0	4	5·4
14th " ..	90	2	0	0	2	2·2
21st " ..	89	3	4	1	8	8·9
28th " ..	134	2	2	1	5	3·7
4th September ..	98	0	3	3	6	6·1
11th " ..	131	4	5	2	11	8·4
18th " ..	88	1	3	1	5	5·7
25th " ..	57	1	1	0	2	3·5
2nd October ..	24	0	0	0	0	0·0
9th " ..	14	0	0	0	0	0·0
Total .	835	17	19	8	44	5·1

It will be observed from Table XV that a high percentage of infection in *A. culicifacies* was observed during the months of August and September. Infections were already occurring in this species when the main survey was

commenced towards the end of July, but, although the survey was commenced too late to determine exactly when infections in this species commenced to appear, it seems probable from the case incidence figures in the military hospitals (*vide* p. 368) that active transmission of malaria was not common prior to the middle of July. Gland infections were found in this species between 1st August and 25th September and it is probable that this was the period during which conditions were most favourable for the transmission of malaria by *A. culicifacies* during the malaria season of 1935. No infections were found in this species after 25th September, and, as the number of adults of this species showed a marked decline after that date, it is improbable that *A. culicifacies* was responsible for the transmission of malaria thereafter, at least to any appreciable extent.

The results of dissections of *A. culicifacies*, classified according to the 'catching areas' from which the adults were collected, are given in Table XVI.

TABLE XVI.

Catching area.*	Number dissected.	Number infected.	Percentage infected.
Hudda village	288	13	4·5
Kotwal and Navagaon villages ..	321	23	7·2
Railway and police lines .	104	4	3·8
Military area	33	1	3·0
Civil Hospital .. .	21	2	9·5
Karezes and hill caves .	59	1	1·7

*For details of these catching areas *vide* Table I.

As in the case of *A. superpictus*, the highest percentage of infection in *A. culicifacies* was found among the adults collected from the Civil Hospital. It is probable that this finding may be accounted to the presence of gametocyte carriers among the patients in the hospital, but the numbers observed were small and are therefore liable to be misleading. The lowest infection rate in *A. culicifacies* was found to occur among the adults collected from outdoor resting-places. This finding is in sharp contra-distinction to similar observations on *A. superpictus* which showed a high infection rate among adults collected from outdoor shelters. The explanation of this difference in the infection rate between these two species probably lies in the fact that *A. culicifacies* is less prone to resort to outdoor shelters after taking a blood meal than *A. superpictus*. The actual numbers of the former species collected from such places were much smaller than in the case of *A. superpictus*, and the indications were that a higher proportion of them were recently hatched specimens.

(*d*) THE DIURNAL RESTING-PLACES OF *A. culicifacies*.

Adult specimens of *A. culicifacies* were collected from a wide variety of resting-places. Although often found to be closely associated with both *A. superpictus* and *A. stephensi*, this species was relatively less abundant in outdoor shelters than *A. superpictus* (*vide* p. 303). The fact that the breeding-places in the vicinity of the outdoor shelters from which adult collections were

made were, if anything, more suitable for *A. culicifacies*, combined with the observation that the females of the latter species were, as a rule, less mature as indicated by the absence of blood in the gut, the stage of development of the ovaries, and the lower infection rate, led us to the conclusion that *A. culicifacies* is more 'domestic' in its habits than *A. superpictus*.

The impression gained during the survey was that *A. culicifacies* exhibited a definite preference for resting-places in close proximity to human habitations. This species was found in large numbers in human and animal houses in villages unaffected by the earthquake, in occupied tents and ruined houses in their immediate vicinity, and in crude shelters erected and occupied by earthquake refugees. Christophers (1933) states that it is often difficult to estimate the numbers of this species present owing to its habit of secreting itself in holes, among dung-cakes, in chaff, etc. It is possible, therefore, that *A. culicifacies* may have been more prevalent in the Quetta area than was indicated by the adult catches. On the other hand, the relative prevalence of this to other species was found to be similar in both adult and larval collections.

If, as we believe, the adults of *A. culicifacies* are more domestic in their habits than those of *A. superpictus*, it seems probable that they would be more exposed to general conditions of temperature and humidity than the last-named species which shows a greater tendency to shelter in outdoor resting-places. *A. culicifacies* may, therefore, be more affected by general atmospheric conditions than *A. superpictus*. The same applies to *A. stephensi* which, as will be shown, is even more domestic in the selection of its resting-places than *A. culicifacies*. These observations are of some practical importance in considering the control of malaria in Quetta, particularly in regard to such methods as the use of insecticidal sprays in dwellings.

(*e*) Dispersion of *A. culicifacies*.

Although there is but little experimental evidence available on the range of flight of the Indian anophelines, it is commonly believed that *A. culicifacies* does not ordinarily disperse to distances much in excess of half a mile. This distance may be extended to as much as a mile in certain circumstances, particularly where dispersal is aided by favourable atmospheric conditions, where food and shelter is scarce or absent nearer at hand, or where breeding of this species is exceptionally intense.

It was not possible during a short survey to make a special study of this subject, but the results of our observations appear to indicate that, in the Quetta area, *A. culicifacies* showed no tendency to disperse to distances much exceeding half a mile. Wherever suitable breeding-places for this species were present in the immediate vicinity, adults were recovered in large numbers, while in other areas where breeding-places were absent, or adequately controlled, within a radius of half a mile or more, adults of this species were absent or extremely scarce. *A. culicifacies* adults were prevalent in the villages of Hudda, Kotwal and Navagaon, relatively scarce in the military area, and extremely scarce in Civil Lines.

Compared with *A. superpictus*, the proportion of male *A. culicifacies* in the adult catches was very much lower. With the exception of some of the outdoor resting-places where this species was found breeding within a few hundred yards, the percentage of males of *A. culicifacies* was generally only about one-third or less of that observed for *A. superpictus*. The explanation of this

difference in the proportion of males in the adult catches of the two species did not appear to be dependent upon the closer proximity of the catching areas to the breeding-places of *A. superpictus* but rather the reverse.

It is not possible to say, from our observations, whether this apparent difference in the proportion of males of these two species is attributable simply to the longer range of flight of the male of *superpictus*, or whether the mating habits of these two species are markedly different. If the higher proportion of males in the adult catches of *A. superpictus* as compared with *A. culicifacies* be attributed to the longer range of flight of the larger and sturdier species, one would expect to find a similar proportion of males in other strong and sturdy species such as *A. turkhudi*. In actual practice, however, the male to female ratio among wild-caught adults of the latter species was strikingly similar to that observed in the case of *A. culicifacies*. Another factor which might be expected to have an influence on this ratio of sexes would be the possibility of the larger and sturdier males surviving for a longer period. While this might be expected to explain the difference in the sex ratios of *A. superpictus* and *A. culicifacies*, it could not be expected to explain a similar difference between *A. superpictus* and *A. turkhudi*, both of which are large, sturdy mosquitoes.

(*f*) Preferential breeding-places of *A. culicifacies*.

The chief breeding-places of the three important malaria-carrying anophelines of the Quetta area have already been analysed in some detail (*vide* p. 314), and it is only necessary here to summarise the preferential breeding-places of *A. culicifacies*.

A. culicifacies was found to show a marked preference for breeding in connection with open irrigation channels arising from springs, wells, rivers, karezes, etc. Breeding was observed chiefly in bays and backwaters along the edges of these channels and in leaks and seepages from them. The number of *culicifacies* larvæ recovered from situations of this type exceeded that for any other species encountered, and amounted to 35 per cent of all the larvæ of this species collected in the Quetta area.

This species also showed a pronounced preference for breeding-places such as pools, ponds, springs, and other collections of still water, in which grassy vegetation was often relatively abundant. In places of this type, which were common in connection with irrigation systems, the actual numbers of *culicifacies* larvæ recovered exceeded those for any other species, and accounted for 33 per cent of all the *culicifacies* larvæ collected from the Quetta area.

A. culicifacies was also found to breed in a variety of other situations but was relatively less prevalent in them. These places include rivers and streams (14 per cent), seepages and marshy areas (8 per cent), and miscellaneous breeding-places such as springs under trees, underground or partially underground karezes, wells, etc. (10 per cent).

3. *A. STEPHENSI.*

(*a*) Geographical distribution.

A. stephensi is essentially an Indian species and has been recorded from outside the Indian area only from Muscat (South Arabia), and from Lower Mesopotamia. This species has a wide distribution throughout the whole of India including Upper Burma, but has not been recorded from Ceylon.

(*b*) Relative and seasonal prevalence of *A. stephensi* in Quetta.

Although not so prevalent in Quetta from July to October as either *A. superpictus* or *A. culicifacies*, *A. stephensi* is, nevertheless, sufficiently prevalent to be a potential danger in the spread of malaria, particularly in certain parts of the Quetta area.

Out of a total adult catch of 7,023 specimens of all species of anophelines, 1,200 (17 per cent) were *A. stephensi*, while of 7,049 bred specimens of all species 1,211 (17 per cent) were found to belong to this species. At the end of July and during the early part of August, *A. stephensi* was slightly more prevalent than *A. culicifacies*, but the latter species soon became the more prevalent of the two, and remained so until the conclusion of the survey. According to Davys (1912) *A. stephensi* makes its first appearance in Quetta towards the end of June, is by no means rare during July, but is not found after the middle of October. Gorman (1933) first observed *A. stephensi* in Quetta cantonment in June, but it was found in only small numbers from June to September. The numbers of adults captured were, however, very small. Furthermore the number of breeding-places suitable for *A. stephensi* are not numerous within the military area.

During the present survey many of the most suitable breeding-places for *A. stephensi* in the vicinity of Quetta were under control by anti-larval measures. This was particularly the case in regard to the extensive breeding-places connected with the numerous springs in the area lying between the railway line and the Lora stream. Had it not been for these control measures, it is probable that *A. stephensi* would have been much more prevalent in this area than was found to be the case.

A sudden fall in the prevalence of this species was observed towards the end of September, and by the early part of October adults of *A. stephensi* were extremely scarce.

(*c*) Relation of *A. stephensi* to the transmission of malaria in Quetta.

With the exception of *A. culicifacies*, and possibly also of *A. minimus* in the eastern parts of India, *A. stephensi* is generally regarded as the most dangerous malaria-carrying anopheline in India. This species is particularly notorious as a carrier of malaria in urban areas to which it appears to be able to adapt itself better than any other Indian anopheline.

A total of 719 specimens of *A. stephensi*, captured in nature between 25th July and 9th October, 1935, was dissected. Of these, 7 (1·0 per cent) were found to be infected. A detailed statement of these dissections, by weekly periods, is given in Table XVII.

At no period during the survey did *A. stephensi* show as high an infection rate as either *A. culicifacies* or *A. superpictus*. No gland infections were detected in this species before the middle of August, and during this time only one infected gut was observed among 360 examined. The dissections of this species which were made from about mid-August to mid-September showed that gut and gland infections were more numerous, the infection rate by weekly periods during this time varying from 1·7 per cent to 2·5 per cent. No infections were observed after the middle of September, but the numbers dissected during the latter period were small owing to the scarcity of adults at this time. From these findings it appears that, during the period of the survey, *A. stephensi*

TABLE XVII.

Showing results of dissections of 719 A. stephensi *by weekly periods.*

Week ending	Number dissected	Number with gut only infected.	Number with gland only infected.	Number with gut and gland infected.	Total number infected.	Percentage infected.
31st July ..	73	0	0	0	0	0·0
7th August ..	139	1	0	0	1	0·7
14th „ ..	148	0	0	0	0	0·0
21st „ ..	100	1	0	1	2	2·0
28th „ ..	51	0	1	0	1	2·0
4th September ..	40	1	0	0	1	2·5
11th „ ..	57	1	0	0	1	1·8
18th „ ..	58	1	0	0	1	1·7
25th „ ..	35	0	0	0	0	0·0
2nd October ..	12	0	0	0	0	0·0
9th „ ..	6	0	0	0	0	0·0
TOTAL ..	719	5	1	1	7	1·0

was probably an effective carrier of malaria for a comparatively short time (about one month). So far as can be ascertained from the data available, it is probable that, during the period under review, *A. stephensi* was not only a less efficient malaria carrier and a less prevalent species than either *A. superpictus* or *A. culicifacies*, but was also concerned in the transmission of malaria for a shorter period than either of these other two species.

As in the case of the other carrier species, the results of dissections of *A. stephensi* showed widely varying infection rates among adults collected from different catching areas. This will be clear from the statement of dissection results shown in Table XVIII.

TABLE XVIII.

Catching area.*	Number dissected.	Number infected.	Percentage infected.
Hudda village	545	2	0·4
Kotwal and Navagaon villages ..	40	1	2·5
Railway and police lines ..	91	2	2·2
Military area	9	0	0·0
Civil Hospital	9	2	22·2
Karezes and hill caves ..	24	0	0·0

* For details of catching areas *vide* Table I.

The highest percentage of infection in *A. stephensi* was observed among the adults collected from the Civil Hospital. This finding coincides with that observed in the other two carrier species, and is probably attributable to the aggregation of gametocyte carriers in the hospital. The vast majority of the *stephensi* adults dissected were collected from Hudda village. The infection

rate among 545 *stephensi* collected from this village was very much lower (0·4 per cent) than was observed in the case of *A. superpictus* (347 dissections) and *A. culicifacies* (288 dissections) in which the infection rates among adults collected from the same place, and over the same period, were 4 3 per cent and 4·5 per cent respectively. It is highly probable, therefore, that *A. stephensi* was a much less efficient malaria carrier in Hudda, at least, than either *A. superpictus* or *A. culicifacies*. The cause for this is not quite clear. It is well known that, in certain parts of India, *A. stephensi* is a highly efficient malaria carrier, while in other parts it appears to be less important. So far as Quetta is concerned, the relative inefficiency of *A. stephensi* as a malaria carrier may be attributable to the presence of a 'race' of *stephensi* which is less androphilic than those which occur in certain other places. On the other hand, the explanation may lie in the relative unsuitability of the Quetta climate for the longevity of this species as compared with the other carrier species, or to the absence of suitable diurnal resting-places. With regard to the latter it will be shown later that *stephensi* showed a more marked preference for resting-places in close proximity to human and animal dwellings than either of the other two carrier species. Only a very small proportion of the adult catches of *A. stephensi* was recovered from outdoor resting-places. It is possible that the latter species may have been less adaptable to the conditions prevailing after the earthquake than the other carrier species, or that the meteorological conditions prevailing during the survey were less suitable for the survival of this as compared with the other carrier species. Our observations during the malaria season of 1935 do not enable us to comment further on these possibilities.

(*d*) The diurnal resting-places of *A. stephensi*.

Although adults of *A. stephensi* were collected from a wide variety of resting-places, this species was found to be much more localised in the Quetta area than either of the other two important carrier species. About five out of every six specimens of *A. stephensi* collected from the Quetta area in the adult stage were captured in Hudda village in which they were found chiefly in the crudely constructed shelters hastily erected by the refugees from the ruined village. *A. stephensi* was the most prevalent species of *Anopheles* in Hudda during the survey, but both *A. superpictus* and *A. culicifacies* were also present in considerable numbers and in about equal proportions.

Out of a total adult catch of 1,200 specimens of *A. stephensi* 1,119 were collected in human habitations, or from situations in their immediate vicinity. The fact that such a large proportion of the adults of this species was collected in the crudely constructed shelters mentioned above, is not considered to indicate any special preference on the part of this species for such places, but is probably attributable to the close proximity of suitable breeding-places for *A. stephensi*.

In other parts of India *A. stephensi* has the reputation of being a 'domestic' species, being commonly found in houses and cowsheds. Our observations in Quetta suggest that this species rested by day close to where it fed at night. This species was rarely found in outdoor resting-places, only 81 out of 1,200 specimens being found in such situations, although other species were absolutely and relatively more abundant, and suitable breeding-places for *A. stephensi* were near at hand. Examination of the comparatively small number of *stephensi* adults collected in outdoor resting-places showed that all of these were probably freshly hatched specimens, since there was no evidence of ovarian

development, malarial infection, or ingested blood. Of the 81 specimens collected from outdoor resting-places, 78 were recovered from karezes situated close to suitable *stephensi* breeding-places.

(*e*) Dispersion of *A. stephensi* in the Quetta area.

It is generally believed that *A. stephensi* does not disperse to long distances from its breeding-places. In the city of Bombay, for example, where *stephensi* is the only carrier species of importance, Covell (1928) noted that 'so remarkably localised is the disease that there may be a serious amount of malaria among the occupants of one set of tenements, whilst a few streets away there is very little evidence of the disease'. In this instance, however, the high density of the population would ensure a sufficient food-supply at close quarters. Stammers and Davys (1912), working in Quetta, observed an exceptionally severe outbreak of malaria in the quarters of a single regiment, while neighbouring units were not heavily infected. *A. stephensi* was found to be the most prevalent anopheline in the heavily infected lines, and the authors attribute the failure of malaria to spread to the adjacent units to the fact that *A. stephensi* did not disperse far from its breeding-places.

The results of our investigations in Quetta are compatible with the belief that *A. stephensi* does not disperse to long distances. Wherever this species was found in appreciable numbers, suitable breeding-places, in which larvæ of this species were abundant, were present in close proximity. In Hudda village, for example, where *A. stephensi* was the most prevalent species of *Anopheles* present, suitable breeding-places, in which larvæ of this species were known to be abundant, were present within a few hundred yards. In other places not more than half a mile distant, the number of *stephensi* adults encountered was remarkably small.

With regard to the proportion of the sexes in the adult catches of *A. stephensi*, the actual numbers of adults collected were, in most cases, too small from which to make any deductions. In Hudda village and in the railway-police lines area where the adult catches of this species numbered 875 and 136 respectively, the percentage of males was found to be 12 per cent and 11 per cent respectively. These figures correspond closely with those for *A. culicifacies* for the same catching areas, but are considerably smaller than those for *A. superpictus* which showed a higher proportion of males. As suitable breeding-places for *A. stephensi* were known to exist in close proximity to both the catching areas mentioned above, it seems unlikely that a relatively low percentage of males in the adult catches can be taken to indicate a long range of dispersal for this species. It seems more probable that the males of *A. stephensi* either die off rapidly, or that they do not seek shelter in close proximity to human dwellings, in appreciable numbers.

(*f*) The preferential breeding-places of *A. stephensi* in Quetta.

The principal breeding-places of *A. stephensi* in Quetta have already been considered in considerable detail along with those of the other two carrier species (*vide* p. 314). Although *A. stephensi* was found to breed in a wide variety of places, this species showed definite preferences in the selection of its breeding-places.

The vast majority of both adults and larvæ of *A. stephensi* collected in the Quetta area were encountered in the tract of land lying between the railway

and the Lora stream. As has already been mentioned this area is particularly rich in natural water outcrops such as springs, seepages, artesian wells, etc. More than three-quarters of all the *stephensi* larvæ collected in the Quetta area were recovered from breeding-places in this locality, and, had it not been for the control measures adopted in this part of Quetta, it is highly probable that this proportion would have been much higher. No other prevalent species of *Anopheles* appeared to be so localised.

Water derived from the sources mentioned above offers a wide variety of breeding-places, and these may differ greatly as regards the velocity of the current, the amount of vegetation, the degree of shade, the depth of the water, etc. It is, therefore, somewhat difficult to account for the localisation of *A. stephensi* in the Quetta area since many of the breeding-places in other parts of the area did not appear to present any essential differences from those in which *A stephensi* was commonly encountered.

In seepages and marshy areas in which there was a gentle flow of water, *A. stephensi* was found breeding in profusion. As a rule green algal vegetation was plentiful in places of this type, and grassy vegetation, where present, was not sufficiently dense to afford any appreciable degree of shade. From such places 38 per cent of all the *stephensi* larvæ collected in the Quetta area were collected. Larvæ of *A. superpictus* were also recovered in large numbers from places of this type.

Larvæ of *A. stephensi* were also commonly found in still water such as reservoirs, pools, wells, springs, subsoil water in cracks and fissures in the ground, etc. The amount of vegetation present in these various places was very variable, but, as a rule, algal growths were plentiful and grassy vegetation, if present, was never dense. From breeding-places included in this category, 21 per cent of all the *stephensi* larvæ collected in the Quetta area were recovered. Larvæ of *A. culicifacies* were also recovered in large numbers from breeding-places of this type.

Breeding of *A. stephensi* was also observed in connection with rivers and streams (17 per cent) where it was frequently collected along with *A. superpictus*, and in irrigation channels (13 per cent) where it was more commonly associated with *A. culicifacies*. A small proportion (11 per cent) of the total number of *stephensi* larvæ collected in the Quetta area was also recovered from other breeding-places among which may be mentioned partially underground kareze channels, shaded springs, etc.

It is well known that *A. stephensi* is the species of Indian anopheline which is capable of adapting itself most readily to the conditions prevailing in large cities in which it may breed in profusion in deep wells, covered cisterns, etc. Special attention was therefore directed to places of this type in Quetta, but in spite of repeated searches, no larvæ of this species were ever recovered from cisterns, deep wells, covered springs, cooling tanks, concrete siphon pits, or other places of this nature. This was a matter of considerable surprise in view of the reputation of this species for breeding in such places in many of the cities in India.

Our observations in Quetta suggest that *A. stephensi* prefers open sunlit breeding-places in which the water is either still or flowing gently, and in which vegetation—particularly Spirogyra—is plentiful. A comparatively small number of *A. stephensi* larvæ was found in partially shaded places, but larvæ of this species were never found in dark places. It is possible that, in the absence of what are its favourite breeding-places, this species might adapt itself

to such places as deep wells, cisterns, covered springs, etc. On the other hand it is possible that, in the relatively cool climate of Quetta, places of the latter type would be too cold for this species. It may be that at an elevation of over 5,000 feet above sea level, and in a locality which is close to the limit of its distribution, this species will only breed in the warmer sunlit breeding-places. In the Hanna valley (average elevation about 6,500 feet), *A. stephensi* was found breeding in only very small numbers, although apparently suitable breeding-places were as numerous as in the vicinity of the Lora stream where *stephensi* larvæ were about seven times as abundant. Larvæ of this species were most plentiful in August, and, with the onset of colder weather, both adults and larvæ showed a sudden and rapid decline. It is not improbable, therefore, that *A. stephensi* is more susceptible to the cold than either *A. superpictus* or *A. culicifacies*.

(*g*) Overwintering of *A. stephensi* in Quetta.

The absolute and relative numbers of *A. stephensi* showed a rapid decline towards the end of September, and by the first week in October this species had practically disappeared. At this time no evidence was obtained that the adults of this species showed any changes suggestive of being preparatory to hibernation, and it seems probable that *A. stephensi* overwinters in one of its immature stages. It is possible, however, that with the advent of the cold weather, the activity of adults of this species may cease, and their presence may be overlooked.

Compared with *A. superpictus* which is a Mediterranean species, the adults of both *A. culicifacies* and *A. stephensi,* which are Indian species, became reduced in numbers much earlier after the onset of the colder weather. Neither of the latter species showed any changes suggestive of hibernating in the adult stage, whereas some evidence was obtained that the adults of *A. superpictus* enter on a state of true hibernation.

4. *A. TURKHUDI.*

(*a*) Geographical distribution of *A. turkhudi.*

In the Indian area *A. turkhudi* occurs chiefly in the north-west, central and western portions of the Peninsula. This species has been recorded from outside India only in the Aden Hinterland and east Persia.

(*b*) Relative and seasonal prevalence of *A. turkhudi* in Quetta.

A. turkhudi was encountered in Quetta throughout the whole period of the survey, but it was never sufficiently prevalent to influence appreciably the spread of malaria, even should it prove to be a carrier. Out of a total adult catch of 7,023 specimens of all species, 255 (3 6 per cent) were identified as *turkhudi,* while of a total of 7,049 bred specimens of all species, 890 (12·6 per cent) were found to belong to this species. The difference between the numbers of wild-caught and bred specimens of *A. turkhudi* were strikingly dissimilar in comparison with the corresponding figures for the more prevalent species.

Although present throughout the whole period of investigation, *A. turkhudi* formed but a small proportion of the total weekly catches (usually about 2 to 5 per cent). It was relatively most prevalent towards the end of August

(8 per cent), but was present in only very scanty numbers by the early part of October.

(*c*) RELATION OF *A. turkhudi* TO THE TRANSMISSION OF MALARIA IN QUETTA.

A. turkhudi has been experimentally infected (oöcysts only) with *P. falciparum* by Stephens and Christophers (1902), but there are no records of dissections of wild-caught specimens of this species in India.

During the present investigation, a total of 255 specimens of *A. turkhudi* was captured in nature, of which 202 were females. Forty-eight of the latter were dissected but none was found to be infected. Although the number of dissections was too small to exclude the possibility of this species being a malaria carrier, the small numbers captured indicate that, even should *A. turkhudi* eventually prove to be a carrier species, it would be of little practical importance in Quetta owing to the relative scarcity of adults. Such evidence as was obtained during the survey suggests that this species is not androphilic.

(*d*) THE DIURNAL RESTING-PLACES OF *A. turkhudi* IN THE QUETTA AREA.

Mention has already been made of the fact that, while the numbers of caught and bred specimens showed a very close correlation for most of the anophelines encountered in Quetta, the number of wild-caught adults of *A. turkhudi* was only about one-third of the bred specimens. This finding suggests that *A. turkhudi* is a less domestic species than any other species found in Quetta, a probability which is supported by the observation that the majority of the adults collected were captured in outdoor resting-places. In the latter situations the percentage of males was much higher (36 per cent), than in indoor resting-places (11 per cent). The majority of the *turkhudi* adults collected from outdoor resting-places appeared to be comparatively recently hatched specimens, and there was no evidence to show that, as in the case of *A. superpictus*, this species fed on human subjects and subsequently sought shelter in outdoor resting-places.

(*e*) DISPERSION OF *A. turkhudi* IN THE QUETTA AREA.

The majority of the *turkhudi* adults which were collected from indoor resting-places were captured either in Hudda village or in the Kotwal-Navagaon group of villages. Suitable breeding-places were present in the vicinity of both these catching areas, and were numerous at distances not exceeding half a mile. It may be mentioned in passing that, after the earthquake, cattle were more abundant in the villages mentioned above than in any other part of the Quetta area, and it is possible that these may have had a special attraction for *A. turkhudi*. In the railway and police lines where cattle were scarce, adults of *A. turkhudi* were remarkably scanty although *A. superpictus*, *A. culicifacies*, and *A. stephensi* were fairly abundant. On the other hand, *extensive* breeding-places for *A. turkhudi* were not present within about a mile of this catching area.

The impression gained during the survey was that *A. turkhudi* did not show any marked tendency to disperse to resting-places in or near human habitations. This species was found in the largest numbers in those villages where cattle were most prevalent, but, in spite of being an exceptionally large

and sturdy species, it was rarely found in resting-places more than about three-quarters of a mile from its favourite breeding-places.

(*f*) The preferential breeding-places of *A. turkhudi* in Quetta.

Although *A. turkhudi* larvæ were recovered from a wide variety of breeding-places in the Quetta area, it showed a very definite preference for certain types of breeding-places. About 83 per cent of all the *turkhudi* larvæ collected during the survey were recovered from breeding-places in connection with rivers and streams.

In the vicinity of the Lora stream considerable numbers of *turkhudi* larvæ were found in the stream itself, about 75 per cent of all larvæ from this locality being found here. The majority of the remainder were collected from small side streams or from marshy areas where there was a definite, though sluggish, flow of water. In this locality *A. turkhudi* exhibited a very definite preference for running water in which there was abundant algal vegetation, but relatively little or no grassy vegetation.

In the Hanna valley *turkhudi* larvæ were commonly recovered from the edges of the main streams which were often rich in dense masses of Spirogyra, even where the central velocity of the streams was swift. They occurred in relatively greater numbers, however, in the shallow, marshy places where the current was sluggish. Practically all the *turkhudi* larvæ collected from breeding-places connected with the Hanna river were recovered from one or other of these two types of breeding-places. A few larvæ of this species were found in pools in the river bed, but it was conspicuous by its scarcity in typical irrigation channels arising from the Hanna river.

A. turkhudi was found breeding in water connected with springs, particularly in those places where there was a sluggish outflow of water, and also in irrigation channels arising from springs especially where the current was relatively slow.

Larvæ of *A. turkhudi* were also recovered occasionally from other types of breeding-places among which may be mentioned subsoil water in cracks and fissures in the ground; kareze water whether in open or partially underground channels; reservoirs and ponds in connection with irrigation water arising from springs and artesian wells, and in the channels arising from similar sources.

No other species of *Anopheles* in the Quetta area was observed to show a more marked preference in the selection of its breeding-places. Flowing water, especially where the flow is sluggish, and where algal growths are abundant, is apparently particularly favoured by this species. Such places were most numerous in connection with the Hanna and Lora streams and, to a lesser extent, with springs. Although the larvæ of *A. turkhudi* may be found at the edges of swiftly running streams, they seem to prefer open sunlit places where the current is sluggish, and where algal vegetation is abundant and grassy vegetation is relatively scanty or absent. This species was commonly found breeding in association with *A. superpictus*.

5. *A. DTHALI.*

(*a*) Geographical distribution of *A. dthali*.

A. dthali has been recorded from Palestine, Sinai, Somaliland, Sudan, south Algeria, the Aden Hinterland, Upper Mesopotamia and Muscat. In the Indian area this species has been recorded only from Baluchistan and the North-West Frontier Province, and this appears to represent its eastern limit of distribution.

(*b*) RELATIVE AND SEASONAL PREVALENCE OF *A. dthali* IN QUETTA.

Although adult specimens of *A. dthali* were captured in the Quetta area throughout the whole period of the survey, they were never sufficiently prevalent to be considered of any practical importance in relation to the transmission of malaria. The adults captured formed only 1·8 per cent of the total adult catch of all species of *Anopheles*, while the bred specimens amounted to only 2 6 per cent of those of all species.

A. dthali was relatively most prevalent towards the end of July, but during July and August it formed only a very small proportion of the total adult catch. Very few specimens were caught after the middle of September.

(*c*) RELATION OF *A. dthali* TO THE TRANSMISSION OF MALARIA.

There is no evidence that *A. dthali* plays any part in the transmission of malaria in any part of the world. This species has been suspected of being a carrier, on epidemiological grounds, in Arabia (Patton, 1905) and in Sinai (Kirkpatrick, 1925). No records of dissections have apparently been made.

Only 70 female specimens of this species were captured during the survey of Quetta. Of these 24 were dissected, but none was found to be infected. Although no information was obtained with regard to the prevalence of this species in Quetta during June and the early part of July, the relative scarcity of adult females during the period of the survey indicates that it is of little or no importance in the spread of malaria in the Quetta area.

(*d*) DIURNAL RESTING-PLACES OF *A. dthali* IN QUETTA.

The number of wild-caught adults of *A. dthali* in the Quetta area is too small to attempt any detailed analysis of its resting-places. Adults of this species were collected from a wide variety of resting-places including houses, tents, crude shelters, animal houses, kareze shafts and tunnels, and caves in hillsides. The number of males in the aggregate adult catch was approximately equal to the number of females. In some places, particularly in resting places of the indoor type, the proportion of males was higher than of females. On the other hand, the females were about three times as prevalent in other situations, particularly in those of the outdoor type. No other species of *Anopheles* in the Quetta area showed such a high percentage of males in the adult catches. In contra-distinction to *A. turkhudi*, the majority of *dthali* adults were collected from indoor resting-places.

(*e*) PREFERENTIAL BREEDING-PLACES OF *A. dthali* IN QUETTA.

The majority (69 per cent) of the *dthali* larvæ collected during the survey were found in breeding-places connected with the Hanna river or the Lora stream. Of the remainder, many were collected from springs and seepages, but small numbers were occasionally found in irrigation channels arising from artesian wells or karezes.

In the vicinity of the Lora stream most of the larvæ (83 per cent) were recovered from the main or side streams, or from marshy areas in which the flow of water was sluggish. Similarly in the vicinity of the Hanna river, most (78 per cent) of the *dthali* larvæ were collected from flowing water. In the Quetta area, *A. dthali* may be said to breed in almost any clean, fresh water varying from still to fast-flowing water, but it exhibited a definite preference for slowly-flowing water rich in algal vegetation, and with or without some grassy

vegetation. In general, the favourite breeding-places of *A. dthali* were found to be very similar to those preferred by *A. turkhudi*. The larvæ and pupæ of *A. dthali* are small in size and may, when disturbed, remain submerged for long periods.

6. *A. SERGENTI.*

(*a*) Geographical distribution of *A. sergenti*.

A. sergenti is widely distributed throughout the Mediterranean region, and extends eastwards through Egypt, Palestine and Syria to the north-west of India where it has been recorded from Waziristan. This species has not previously been recorded from Quetta.

(*b*) Relative and seasonal prevalence of *A. sergenti* in Quetta.

During the period of the survey, the number of adults of *A. sergenti* captured formed only 1 per cent of the total catch for all species. Of these, about 70 per cent were collected from kareze shafts, and the remainder from resting-places in or near human habitations. Only fourteen specimens were identified from the larval catches.

No specimens of *A. sergenti* were encountered prior to the middle of August, but after this time small numbers were present for the remainder of the period of the survey.

(*c*) Relation of *A. sergenti* to the transmission of malaria.

Although a proven malaria carrier in Palestine (Kligler, 1930), *A. sergenti* does not occur in sufficiently large numbers in Quetta to be considered of any practical importance in the spread of malaria. Only 6 specimens were dissected, but none of these was found to be infected.

(*d*) Breeding-places of *A. sergenti* in Quetta.

Of the 14 specimens of *A. sergenti* identified from larvæ, 11 were collected from shallow, flowing, water associated with rivers, springs or seepages. In these places algal vegetation was plentiful, but grassy vegetation was scanty or absent. Two were collected from the edges of swiftly-flowing streams where dense algal growth was present, and one was recovered from an open irrigation channel arising from a kareze.

7. *A. MULTICOLOR.*

(*a*) Geographical distribution of *A. multicolor*.

A. multicolor is a desert species which has a wide distribution from the Sahara to Baluchistan. In the Indian area it has been recorded only from the Persian frontier and Baluchistan. Its occurrence in Quetta may therefore be regarded as being close to the eastern limit of its distribution.

(*b*) Relative and seasonal prevalence of *A. multicolor* in Quetta.

Only 21 adult specimens of *A. multicolor* were captured in Quetta during the survey, and only 8 were reared from larvæ. No adults were captured before mid-August, but this species was present in small numbers for the remaining period of the survey. Larvæ were collected between mid-August and mid-September. Adults were collected from both indoor and outdoor resting-places, being rather more numerous in the latter.

(c) Relation of *A. multicolor* to the transmission of malaria in Quetta.

A. multicolor has been suspected of being a malaria carrier on epidemiological grounds, but there appear to be no records of its having been found infected in nature. No dissections of this species were made in Quetta, but it is evident that, owing to its extreme scarcity, it is of no practical importance.

(d) Breeding-places of *A. multicolor* in Quetta.

Larvæ of *A. multicolor* were found only in the vicinity of the Lora stream. All were recovered from slowly-flowing water rich in algal vegetation. It is said that the water in this area is highly saline, but no steps were taken to confirm this.

8. *A. PULCHERRIMUS.*

(a) Geographical distribution of *A. pulcherrimus.*

A. pulcherrimus has been recorded from Caucasus, Mesopotamia, Persia, Turkestan, Bokhara, and the north-west of India (Baluchistan, N. W. F. P., Sind, Gujerat, and the western portion of the United Provinces).

(b) Relative and seasonal prevalence of *A. pulcherrimus* in Quetta.

During the period of the survey only 29 specimens of *A. pulcherrimus* were encountered in Quetta. Of these, 20 were captured as adults, and 9 were reared from larvæ. The majority of the adult specimens were collected in tents and ruined buildings in their immediate vicinity. A few were also caught in human habitations in villages, and in kareze shafts.

(c) Relation of *A. pulcherrimus* to the transmission of malaria in Quetta.

Although *A. pulcherrimus* has been found infected in nature in Central Asia and Sind, it is so scarce in the Quetta area as to be of no practical importance in the spread of malaria. No dissections were made during the survey.

(d) Breeding-places of *A. pulcherrimus* in Quetta.

Larvæ of *A. pulcherrimus* were recovered from pools and marshy areas in which the current was sluggish.

9. *A. FLUVIATILIS.*

(a) Geographical distribution of *A. fluviatilis.*

A. fluviatilis is essentially an Indian species, and has been recorded from outside the Indian area only from Siam, Tonkin and Turkestan. In India this species has a wide distribution, but it occurs chiefly in mountainous and submontane tracts.

(b) Relative and seasonal prevalence of *A. fluviatilis* in Quetta.

Only 23 specimens of *A. fluviatilis* were identified from the Quetta area during the survey. Of these, 13 were captured as adults and 10 were reared from larvæ. The adults were collected from both indoor and outdoor resting-places. A single adult specimen was captured at the end of July, and the remainder at the end of August and the beginning of September, after which this species was not again encountered.

(*c*) Relation of *A. fluviatilis* to the transmission of malaria in Quetta.

A. fluviatilis is regarded as an important malaria carrier in certain parts of India, but its extreme rarity in Quetta during the greater part of the malaria season suggests that this species is of no practical importance as a malaria carrier in this locality.

(*d*) Breeding-places of *A. fluviatilis* in Quetta.

All the larvæ of *A. fluviatilis* which were collected in the Quetta area were recovered from irrigation channels arising either from artesian wells or karezes.

10. *A. SUBPICTUS.*

(*a*) Geographical distribution of *A. subpictus.*

A. subpictus has an almost universal distribution throughout India and Ceylon, and extends eastwards as far as the Philippines. Its occurrence in the Quetta area is close to the western limits of its distribution.

(*b*) Relative and seasonal prevalence of *A. subpictus* in Quetta.

Only 13 specimens of *A. subpictus* were identified in Quetta during the whole period of the survey. Of these, ten were collected as adults (tents and refugee shelters), and three were reared from larvæ collected from seepage water and from an irrigation channel. This species was captured only between mid-August and mid-September.

(*c*) Relation of *A. subpictus* to the transmission of malaria in Quetta.

Apart from the fact that *A. subpictus* has never been found to be a malaria carrier, the numbers encountered in Quetta were too small to influence the spread of the disease.

11. *A. LINDESAYI.*

(*a*) Geographical distribution of *A. lindesayi.*

The type form of *A. lindesayi* has been recorded only from India where it occurs chiefly in the montane tracts of the northern areas, usually at elevations of 4,000 feet or more. Baluchistan probably represents the westerly limit of distribution of this species.

(*b*) Relative and seasonal prevalence of *A. lindesayi* in Quetta.

Only 7 adult specimens of *A. lindesayi* were captured in Quetta during the survey, of which six were collected from tents and one from a hill cave. Larvæ of this species were recovered from deep, still, and heavily shaded water at the head of a kareze. This species was encountered in Quetta only during the month of September.

(*c*) Relation of *A. lindesayi* to the transmission of malaria in Quetta.

A. lindesayi is not considered to be a carrier of malaria in nature, and with regard to Quetta its scarcity eliminates it as a factor of practical importance.

12. *A. MOGHULENSIS.*

(*a*) Geographical distribution of *A. moghulensis.*

A. moghulensis has been recorded with certainty only from the Indian area, where it occurs chiefly in the central and western portions of the Peninsula, in the north-west and in Baluchistan. It may occur also in Turkestan.

(*b*) RELATIVE AND SEASONAL PREVALENCE IN QUETTA.

No adults of *A. moghulensis* were encountered in any of the anopheline resting-places investigated in the Quetta area, but a total of 35 larvæ was collected during July and August.

All the larvæ of this species were recovered from breeding-places in which the flow of water was sluggish, and where short grassy vegetation was present and Spirogyra was abundant. Larvæ were collected both from the Hanna valley, and from the Lora stream and places in its immediate vicinity.

Nothing appears to be known with regard to the malaria-carrying powers of this species. In Quetta it is so rare as to be of no importance in the transmission of malaria.

13. *A. HABIBI.*

A species of *Anopheles* which could not be identified as any of the known Mediterranean, Oriental or Indian species, was encountered during the survey. A full description of this species has been given by Mulligan and Puri (1936) who have named it *A. habibi.*

Only one adult specimen was collected, and only one larva was recovered during the whole period of the survey. This indicates that this species is very rare in this area, and is therefore of no practical importance. The adult specimen was captured in Hudda village, and the larva was recovered from an irrigation channel arising from an artesian well partially shaded by the trees in Galbraith Spinney. *A. habibi* was the only species of *Anopheles* with unspotted wings found in Quetta.

IV. THE INTENSITY AND DISTRIBUTION OF MALARIA IN QUETTA.

1. CONDITIONS AND METHODS OF INVESTIGATION.

During the present investigation, it was possible to obtain much valuable information regarding the amount and distribution of malaria in Quetta, from a spleen census of the local children. Splenic measurements, where recorded, were made by the method described by Christophers and Khazan Chand (1924). Unfortunately, objections were raised to the taking of blood films, and attempts to obtain them were eventually abandoned as they threatened to interfere with the spleen census which, on the whole, is probably the more informative examination.

During the short preliminary survey of the Quetta area which was carried out in May 1935, immediately prior to the occurrence of the earthquake, a spleen census was taken of 427 children (2 to 10 years) resident in or near Quetta. Care was taken to ensure that the children selected for examination were representative of the static population, and where school children were examined, information was elicited regarding the place of residence, and the recent movements, of each individual child.

Following the earthquake, the wholesale destruction of houses, and the plight of many of the refugees, were responsible for a certain amount of movement among the local inhabitants. In some places, however, especially in those least affected by the earthquake, no movements of the population took place, but, in other instances, refugees formerly resident in comparatively healthy localities took up temporary residence in less salubrious areas. Some of the latter returned to the sites of their former residence before the conclusion

of the survey. A good example of this was seen in the case of the inhabitants of the Kasi and Nachari villages among whom the marked increase in the incidence of malaria between May and September was probably due largely to malarial infections acquired during their temporary residence in more highly malarious areas.

In considering the results obtained from spleen examinations in Quetta, several factors must be taken into account. During the malaria season of 1935 (after the earthquake) anti-malaria measures were instituted in some localities but not in others, and these were, in some cases, carried out with such thoroughness that they probably had a considerable influence in reducing the amount of malaria transmission. Apart from such temporary movements of the local inhabitants as have been referred to above, it is necessary to distinguish between the type of population which is permanently and continuously resident in the Quetta area (static population), and that which must be regarded as a floating one (non-static population). In the latter case it is impossible to estimate with any degree of accuracy the average period of residence, but, in the case of a section of the civil population at least, this does probably not exceed a year or two, and is frequently considerably less.

An attempt has been made to classify the various villages examined in accordance with these factors, so as to indicate the probable degree of malarial prevalence in localised areas under natural conditions. Since the number of children available for examination in isolated villages was very small, it has been found convenient to consider them in groups of two or more villages, and, wherever possible, to compare and contrast the findings in the malaria and non-malaria season.

2. RESULTS OF SPLEEN CENSUS TAKEN IN THE QUETTA AREA.

(*a*) STATIC POPULATION.

Those children who, according to the local information obtained, had resided permanently and continuously in the Quetta area prior to the earthquake have been classified as 'static population'. In some instances such children were known to have changed their locality of residence temporarily following the earthquake, and where this was found to have been the case, the occurrence has been noted. The children examined for splenic enlargement who have been classified as belonging to the static population have been divided into six groups, each of which is considered below.

(*i*) *Group A.*

This group includes the Kotwal-Navagaon villages situated north-west of the cantonment, and also the villages lying north of Beaty Road and situated between the railway line and the Lora stream (*vide* Map). The nine villages included in this group are enumerated in Table XIX which also gives details of the results of spleen examinations in each village. The results have been given separately for the malaria and non-malaria seasons where this information is available.

These villages may be said to have been uninfluenced by any malaria control measures carried out during the malaria season. This part of the Quetta area was less affected by the earthquake than many others, and there were no noteworthy movements of the inhabitants following the earthquake.

TABLE XIX.

Villages.	Non-malaria season.					Malaria season.				
	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm.	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm
Tarin Shahr ..	..	..	..	..	..	19-9-35	27	19	70	9·1
Navagaon ..	}					"	23	20	87	7·4
Kotwal Khanan	} 17-5-35	50	38	76	9·1	"	20	19	95	7·2
Kotwal ..	}					"	20	19	95	9·0
Kotwal Mohd Umar.	..	..	..	..	..	"	26	20	77	9·7
Kili Shabo ..	..	..	..	..	..	20-9-35	25	22	88	7·3
Kili Mohd Umar	..	..	..	..	..	"	21	15	71	10·0
Kili Sultan ..	..	..	..	..	..	"	13	11	85	8·9
Kili Ismail ..	18-5-35	35	4	11	..	21-9-35	35	24	69	10·0
TOTAL ..	..	..	..	..	..	..	210	169	80	8·9

Only a small number of children was examined in this area during the non-malaria season, but it is clear that there was a high incidence of malaria in the Kotwal-Navagaon villages at this time, and that this showed a considerable increase during the malaria season. This group of villages lies near the cantonment boundary and shows a higher incidence of malaria than any of the other villages in Group A.

In May 1935, the spleen rate in the village of Kili Ismail was only 11 per cent, but this had increased to 69 per cent by September 1935. At the time of the latter visit the small size of the average enlarged spleen (10 cm.) suggests that many of the malarial infections had been recently acquired. This village is probably the least malarious one in Group A, but it is liable to severe exacerbations such as evidently occurred during the malaria season under consideration.

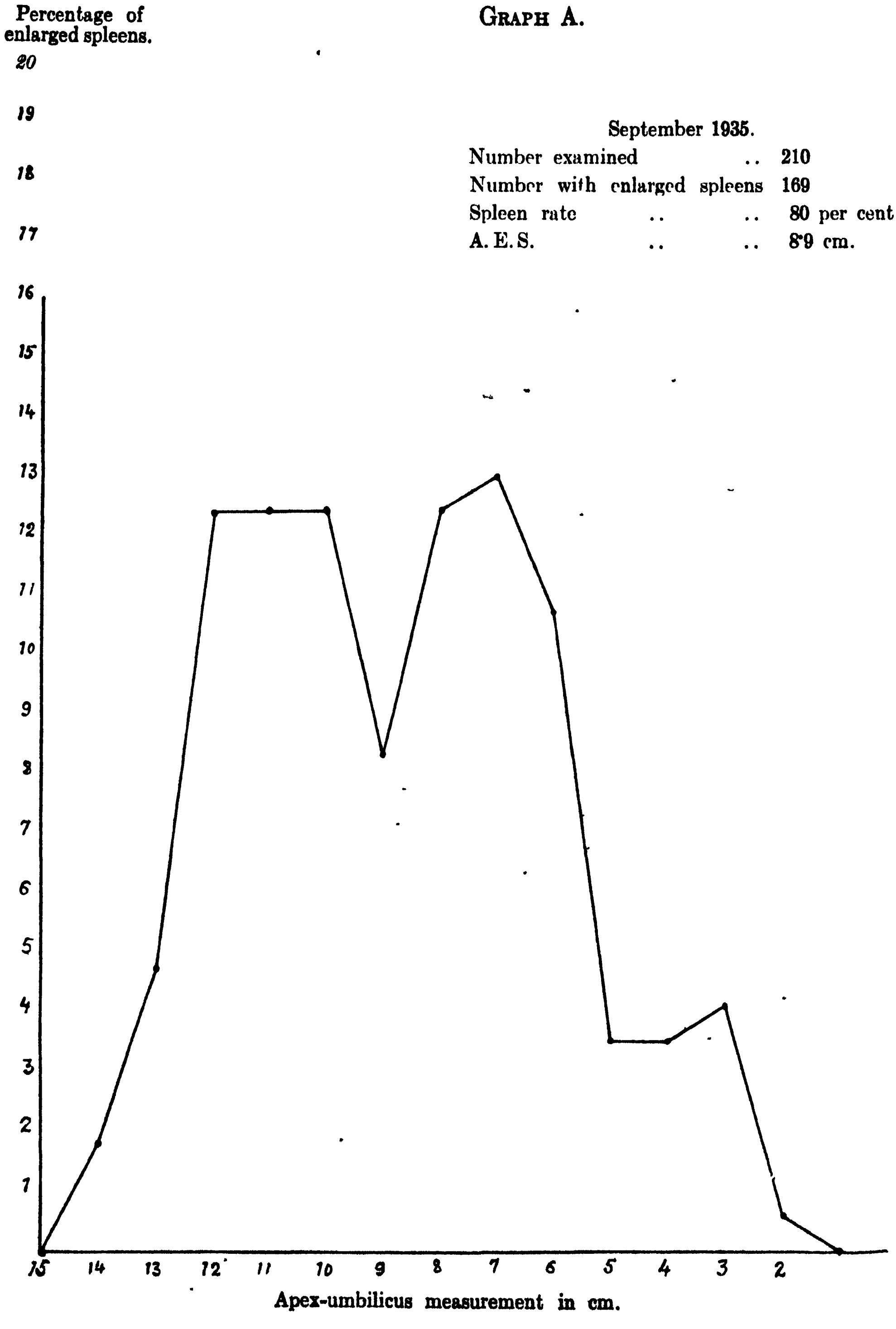
The villages included in Group A are, on the whole, highly malarious ones. Of a total of 210 children examined in this area during the malaria season, the spleen rate was found to be 80 per cent, and the average enlarged spleen 8·9 cm. The frequency distribution of the enlarged spleens has been shown graphically in Graph A from which it will be observed that the curve is bimodal. The first mode at 10 to 12 cm. probably represents a proportion of comparatively recent infections, while the second mode at 6 to 8 cm. indicates the presence of chronic infections, many of which probably represent residual infections from previous years.

The cause of the high incidence of malaria in the villages in Group A is, in our opinion, largely attributable to the proximity of uncontrolled irrigation

GRAPH A.

September 1935.

Number examined	..	210
Number with enlarged spleens		169
Spleen rate	.. ..	80 per cent
A. E. S.	.. ..	8·9 cm.



channels and reservoirs, arising from karezes and from the Hanna river. In the more westerly villages the intense anopheline breeding in the Lora stream is probably partly responsible for the high incidence of malaria.

(*ii*) *Group B.*

Included in this group are seven small villages lying within an area bounded on the north by Beaty Road, on the south by Brewery Road, on the east by the railway, and on the west by the Lora stream (*vide* Map). These villages are enumerated in Table XX which gives details of the splenic examinations carried out during the malaria and non-malaria seasons.

TABLE XX.

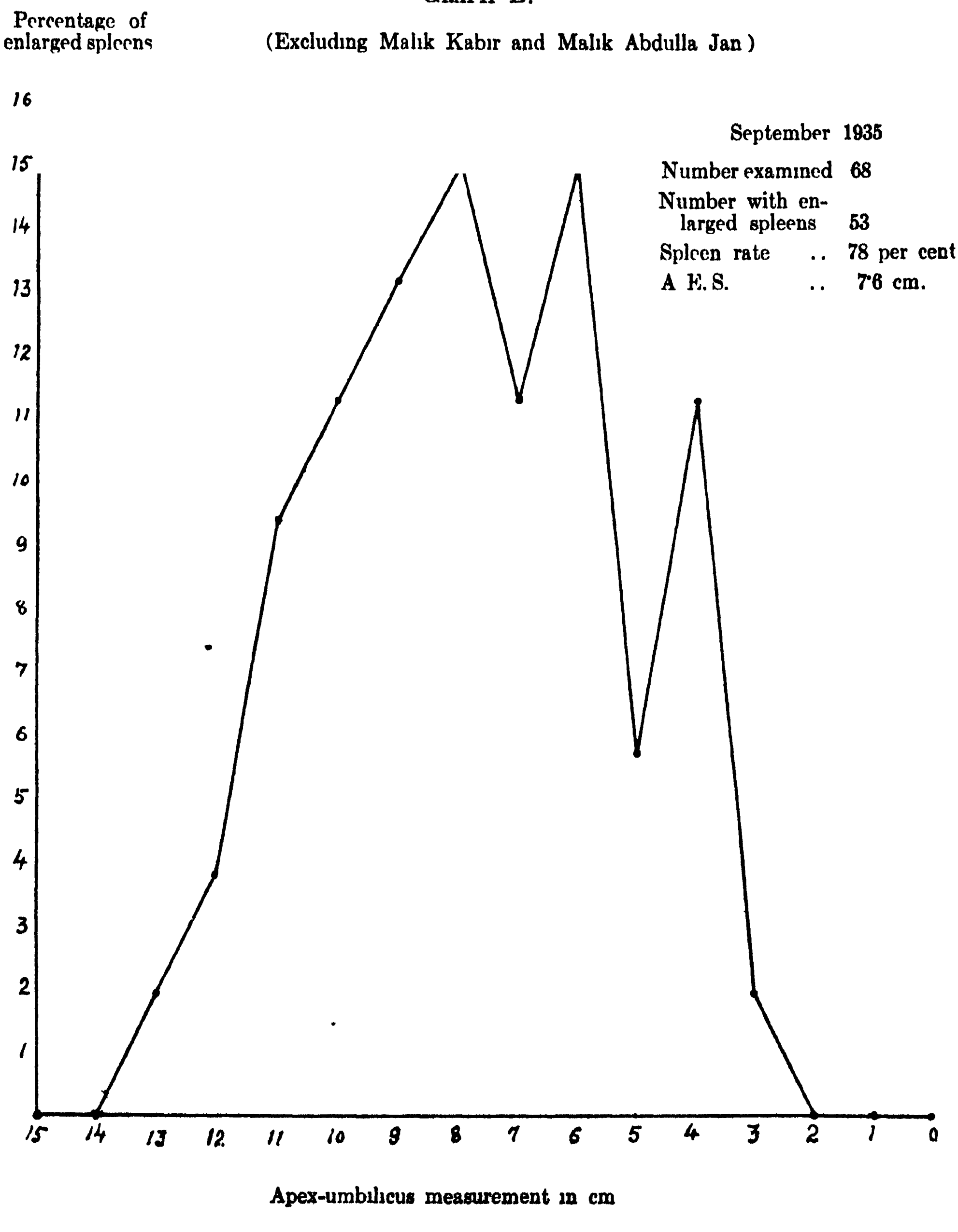
Villages.	Non-malaria season.					Malaria season.				
	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm.	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm.
Malik Abdulla Jan.	..	..	..	..	..	20-9-35	8	7	87	11·7
Kili Malik Kabir	..	..	..	..	..	21-9-35	31	20	68	9·6
Kili Haji Khan	28-5-35	60	47	78	..	,,	10	8	80	9·5
Deda ..						23-9-35	25	17	68	7·7
Yakao ..						25-9-35	17	13	76	7·8
Malik Barkhurdar						23-9-35	16	15	94	6·9
Tarkha ..										
TOTAL ..	..	..	..	..	..	..	107	80	75	8·5

In this area, the chief anopheline breeding-places were controlled during the greater part of the malaria season. So far as our observations indicate, it seems probable that these control measures were effective in preventing a marked increase in the prevalence of malaria during the malaria season of 1935. Excluding the two villages in Group B which were not examined in May 1935 (Malik Abdulla Jan and Malik Kabir) the remaining villages in this group may be considered collectively. In May 1935, the spleen rate among the children examined in these five small villages was 78 per cent (average enlarged spleen not determined) while in September of the same year the spleen rate was again found to be 78 per cent and the average enlarged spleen 7·6 cm. The frequency distribution of enlarged spleens in these five small villages in September 1935 is shown in Graph B, from which it will be seen that the mode occurs at 6 to 8 cm. The number of small spleens (10 to 13 cm.) is relatively small, while there is a fair proportion of spleens of large size (less than 6 cm.).

These findings indicate that this area is a highly malarious one, but that the anti-malaria measures adopted during the malaria season under consideration were probably effective in preventing a marked increase in the malarial incidence. The paucity of small spleens suggests that the number of fresh infections acquired was not large.

GRAPH B.

(Excluding Malik Kabir and Malik Abdulla Jan)



In contrast to the findings in the five villages considered above, those in the other two villages in Group B (Abdulla Jan and Malik Kabir) show that while the spleen rate in both was high (87 per cent and 68 per cent respectively), the size of the average enlarged spleen was small in both (11·7 cm. and 9·6 cm. respectively). It seems possible that in both these villages many of the malarial infections were recently acquired. In this connection it is interesting to note that these two villages are situated at the periphery of the Group B area, and while being further removed from some of the dangerous breeding-places in this area under natural conditions, they were probably less influenced by the control measures carried out in this area in 1935 than the villages nearer the centre.

In all 107 children were examined in Group B in September 1935. The spleen rate for the area as a whole was 75 per cent, and the average enlarged spleen 8·5 cm. These findings agree closely with those observed in Group A but as intensive anti-malaria measures were carried out in the former area and not in the latter, it may be inferred that, under natural conditions, Group B is the more highly malarious of these two areas. It is probable, indeed, that the Group B area, under natural conditions, represents the most highly malarious tract in the vicinity of Quetta.

(*iii*) *Group C.*

Included in Group C are six small villages lying within an area bounded on the north by Brewery Road, on the east by the railway line, on the west by the Lora stream, and extending southwards to Galbraith Spinney and beyond it (*vide* Map). Examination of the children in these villages was carried out on one occasion only (September 1935). The results are given in Table XXI in which the individual villages examined are also enumerated.

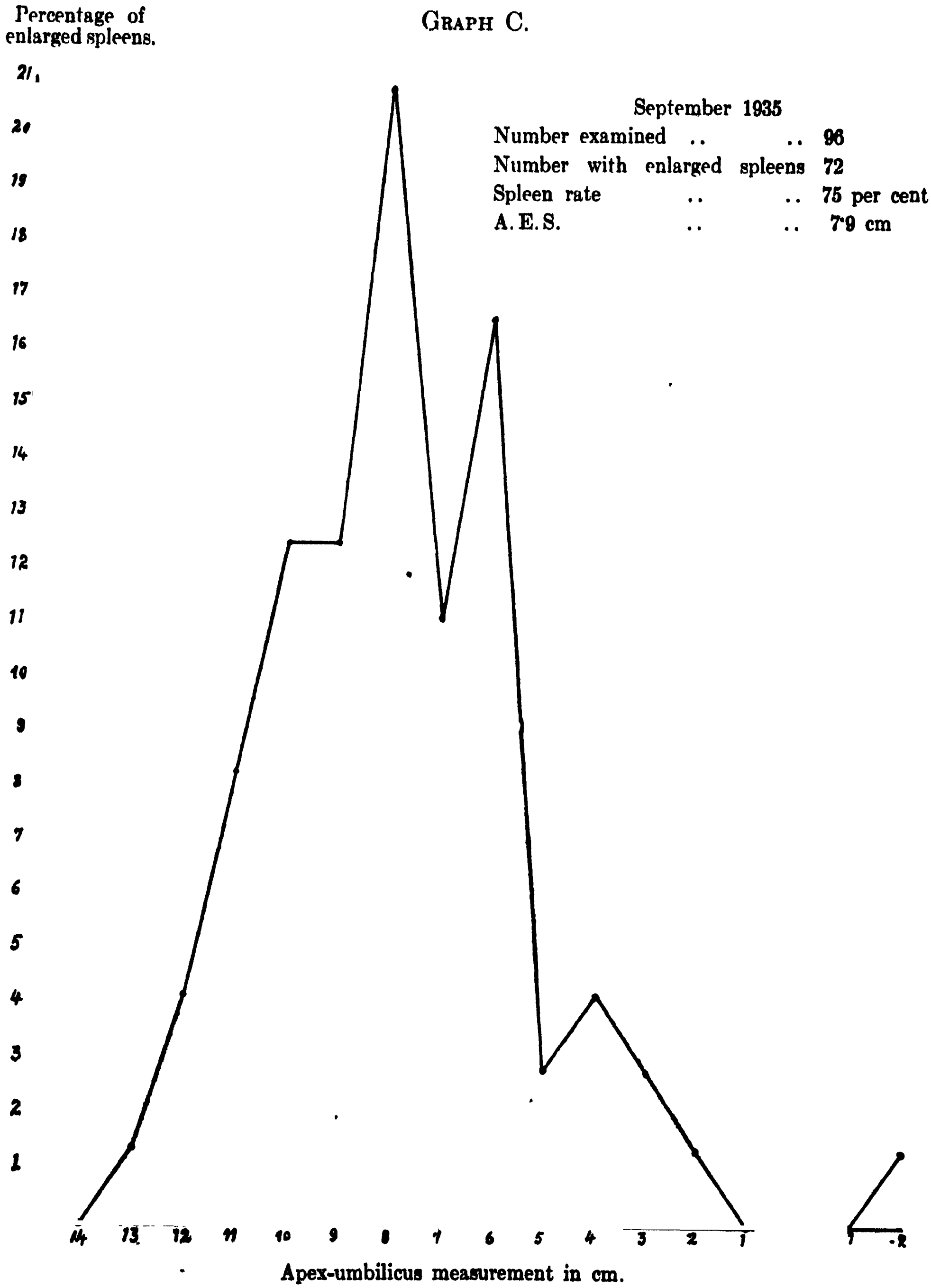
TABLE XXI.

Villages.	MALARIA SEASON				
	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm
Brahmzai	23-9-35	14	10	71	7·9
Kili Shekhan ..	"	20	15	75	7·6
Jio	25-9-35	11	5	45	7·4
Kuz Bagh ..	"	3	3	100	9·0
Kili Mohd Wazir Khan	"	6	5	83	8·4
Ahmed Khan Zai ..	"	42	34	81	7·8
TOTAL ..	..	96	72	75	7·9

The incidence of malaria in some of the villages in this group was probably influenced to some extent by anti-malaria measures, though these were operative only in parts of this area, and were not nearly so complete as in the Group B area.

A total of 96 children was examined in this area among whom the spleen rate was 75 per cent, and the average enlarged spleen 7·9 cm.

GRAPH C.



The frequency distribution of the enlarged spleens observed in these six villages is shown in Graph C, from which it will be seen that the mode occurs between 6 and 8 cm. These findings indicate that the villages in Group C are highly malarious. Compared with the villages in Groups A and B, and remembering the fact that some of the most dangerous anopheline breeding places were controlled for the greater part of the malaria season, it seems probable that the incidence of malaria in the villages included in Group C would be almost as high, under natural conditions, as in Groups A and B.

(*iv*) *Group D.*

This group includes only two villages (Luwar Kareze and Sirki) which are situated to the south of Quetta city and east of the railway line (*vide* Map). These two villages were each examined on two occasions (*i*) early in the malaria season, and (*ii*) late in the malaria season. At the first examination (August 1935) the spleen rates were 35 per cent and 51 per cent respectively, while seven weeks later (September 1935) these had risen to 70 per cent and 79 per cent respectively. Details of these examinations are given in Table XXII.

TABLE XXII.

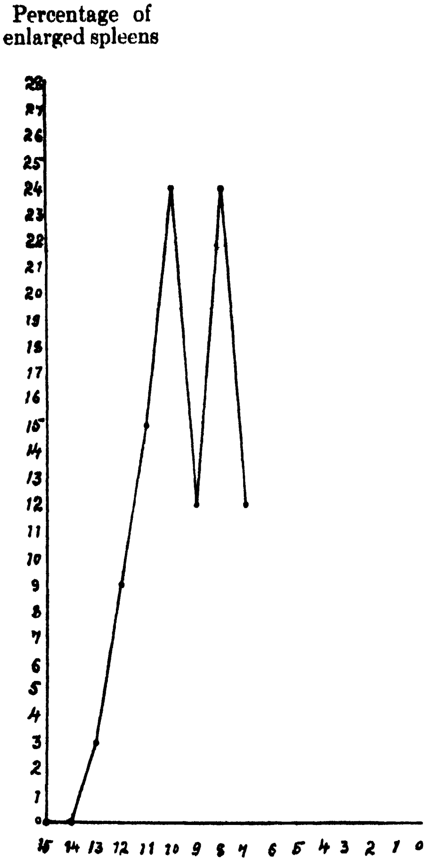
Villages	Early malaria season.					Late malaria season.				
	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm.	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm.
Luwar Kareze ..	1-8-35	17	6	35	9·2	23-9-35	27	19	70	9·3
Sirki ..	"	53	27	51	9·5	"	42	33	79	9·0
TOTAL ..	..	70	33	47	9·2	..	69	52	77	9·0

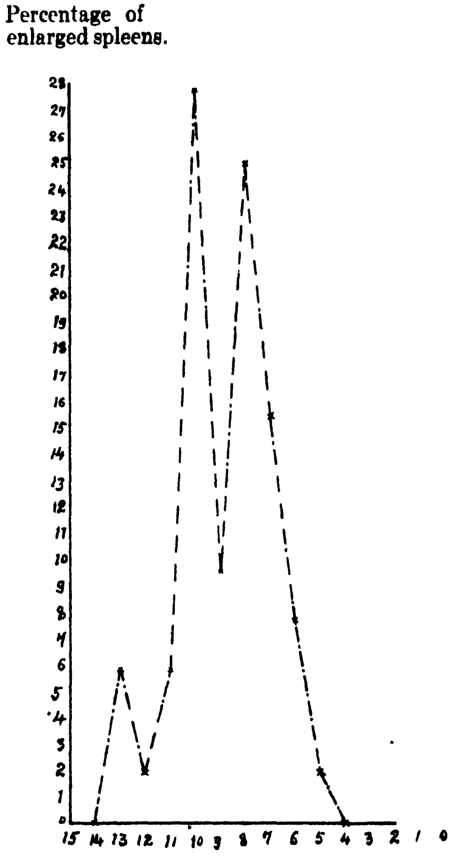
The frequency distribution of the average enlarged spleens in these two villages are shown separately for the early and late malaria seasons in Graph D.

The marked increase in the incidence of malaria which was observed in these two villages during the malaria season affords ample evidence that active malaria transmission was going on in the interval between the two examinations. The small size of the average enlarged spleen in both villages suggests that much of the malaria in this area had been recently acquired. No control measures were in force in this locality, and it is probable that the incidence of malaria in these two villages is usually appreciably less than in Group A, B or C, under natural conditions.

GRAPH D.

	1st August, 1935.	23rd September, 1935.
Number examined ..	70	69
Number with enlarged spleens ..	33	52
Spleen rate ..	47 per cent	77 per cent
A. E. S. ..	9·2 cm.	9·0 cm.





Apex-umbilicus measurement in cm.

(*v*) *Group E.*

This group embraces Quetta city and the villages of Kasi and Nachari which are situated on its south-easterly boundary (*vide* Map). In May 1935, immediately prior to the occurrence of the earthquake 329 children were examined in this locality, of whom 241 were primary school children*, and 88 who were

* The spleen rate among the primary school children was 11 per cent. Histories elicited from each individual child showed that all were resident in Quetta city. The adolescent spleen rate among secondary school children (12 to 16 years) was 22 per cent. Many of those with enlarged spleens were resident in surrounding villages.

examined locally in the Kasi-Nachari area. The spleen rate was ascertained to be 11 per cent and the average enlarged spleen 8·8 cm.

After the occurrence of the earthquake practically the whole of this area was evacuated. Many of the inhabitants of the city were either killed or left Quetta, while many of the survivors from the Kasi-Nachari area sought shelter in other localities (mostly in Group B area). Early in September 1935 the villages of Kasi and Nachari were partially re-occupied, and a spleen census of the children was taken on 20th of the same month. Among 371 children examined on the latter date, the spleen rate was found to be 31 per cent and the average enlarged spleen 9·2 cm. These findings indicate that, so far as can be judged from the information obtained, there was a considerable increase in the incidence of malaria among the population of this area between May and September 1935. It is probable, however, that much of this malaria was acquired during the period of temporary residence of the Kasi and Nachari villagers in the highly malarious Group B area. Details of the spleen examinations made in the Group E area in the malaria and non-malaria seasons are given in Table XXIII.

TABLE XXIII.

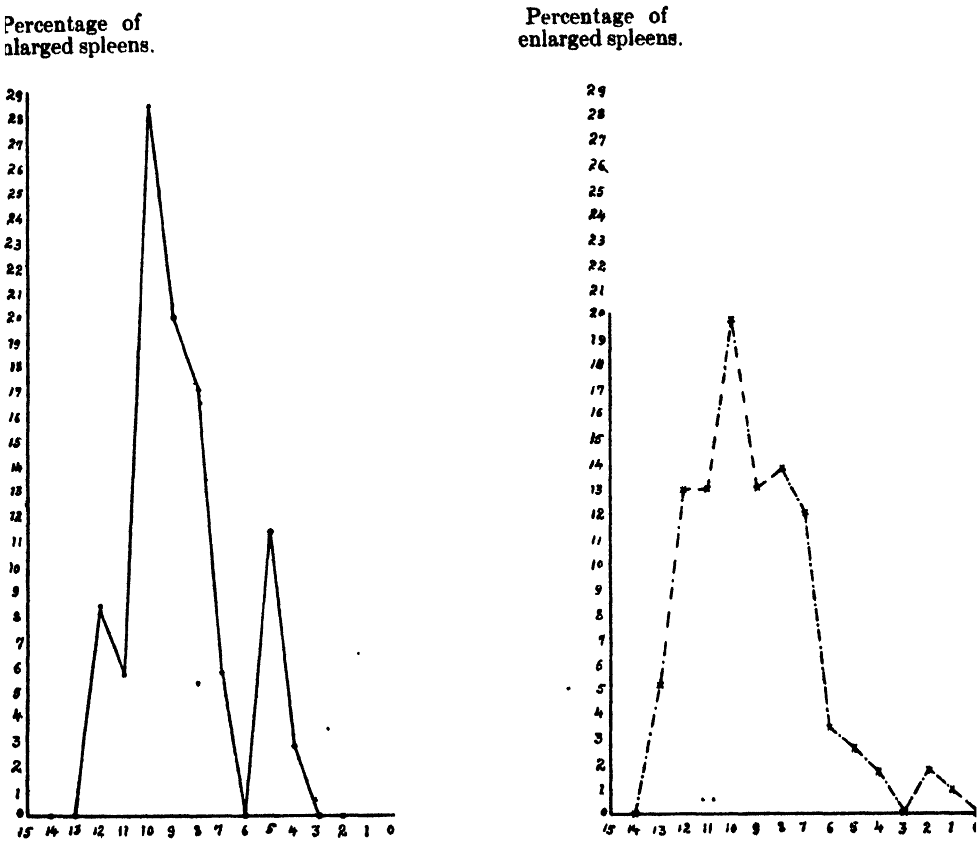
Population.	Non-malaria season.					Malaria season.				
	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm.	Date of examination.	Number examined.	Number with enlarged spleen.	Spleen rate.	Average enlarged spleen in cm.
Kasi and Nachari	20-5-35	88	10	11	9·0	26-9-35	371	116	31	9·2
Quetta city ..	"	241	26	11	8·7	..	..	..	..	..
TOTAL ..	..	329	36	11	8·8	..	371	116	31	9·2

The frequency distribution of the enlarged spleens is shown in Graph E from which it will be seen that, at both examinations, the mode occurred at 10 cm. This preponderance of small spleens suggests a relatively low degree of malarial endemicity among this urban population.

The incidence of malaria among the population resident in Group E is low in comparison with that which was observed in other parts of the Quetta area. It seems probable that the increase of malaria, which occurred during the malaria season under review, was greater than might have been the case had it not been necessary for many of the refugees to seek shelter in less salubrious localities, during the period when malaria transmission was going on.

GRAPH E.

	20th May, 1935.	26th September, 1935
	•———•	×—.—.—×
Number examined ..	329	371
Number with enlarged spleens ..	36	116
Spleen rate ..	11 per cent	31 per cent
A. E. S ..	8·8 cm.	9·2 cm.



Apex-umbilicus measurement in cm.

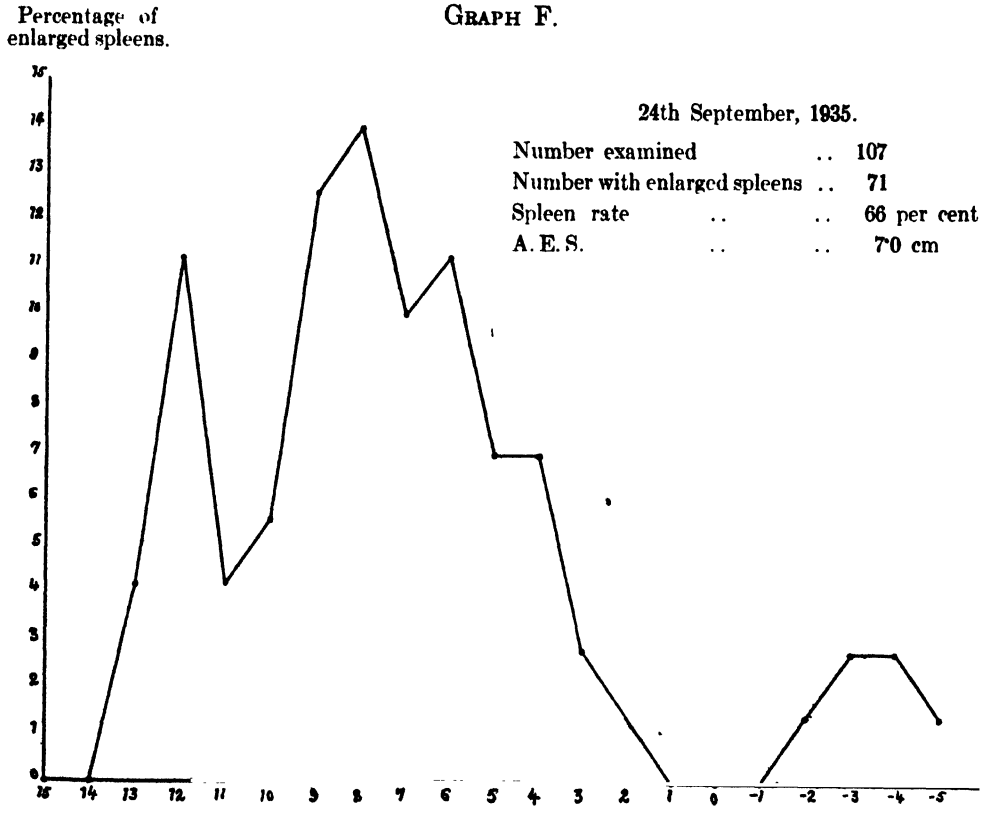
(*vi*) *Group F.*

The children considered in this group are those which were examined in the Hanna valley. Owing to objections raised by the local inhabitants to our visiting individual villages, all spleen examinations were carried out in fields, on roads, etc. Information was elicited from each child as to the exact place of residence.

On 24th September, 1935, 107 children were examined in this valley, their places of residence varying from Hanna Tangi (near Quetta) to Urak

(11 miles from Quetta). The spleen rate was found to be 66 per cent, and the average enlarged spleen 7·0 cm. Since the locality of residence of individual children varied from about 6,000 feet to about 7,000 feet above sea level, the records of the spleen examinations have been subdivided into three groups. At the lower (Quetta) end of the Hanna valley (Hanna Tangi) the spleen rate among 35 children examined was 83 per cent, and the average enlarged spleen 6·2 cm. In the middle region of the valley the spleen rate among 30 children examined was 63 per cent, and the average enlarged spleen 8·0 cm., while at the upper (Urak) end of the valley the spleen rate among 42 children was 55 per cent and the average enlarged spleen 8·2 cm. These results show that the incidence and intensity of malaria becomes progressively less as one proceeds up the valley towards Urak. It is probable that the reason for the lower malarial incidence in the upper parts of the valley is associated with less favourable climatic conditions for adult anophelines. So far as our observations went, there was no indication that anopheline breeding-places were less numerous, less favourable, or more distant from human habitations, in the upper, as compared with the lower, part of the valley.

GRAPH F.



Apex-umbilicus measurement in cm.

The frequency distribution of enlarged spleens observed in the Hanna valley is shown in Graph F from which it will be seen that the mode occurs

at 8 cm. The records from which this curve has been compiled show that the majority of the smaller spleens were observed among children resident in the upper and relatively less malarious parts of the valley.

The Hanna valley is, on the whole, an intensely malarious one. From the practical point of view the chief interest in these observations in relation to Quetta is the danger to which troops are exposed while camping in this area during the malaria season. From the scientific point of view it is enlightening to find such a high incidence of malaria among a population residing at elevations ranging between 6,000 and 7,000 feet above sea level. The most prevalent species of *Anopheles* in the Hanna valley, and undoubtedly the chief malaria carrier, is *A. superpictus*.

(*b*) Non-static population.

In addition to the spleen examinations which were carried out among the more or less permanent population of the Quetta area, a spleen census was also taken of a number of children whose period of residence in Quetta was probably more temporary. These may be conveniently considered in two groups, (*i*) children resident in the railway quarters, and (*ii*) children resident in the villages of Hudda and Habib.

(*i*) *Children resident in the railway quarters.*

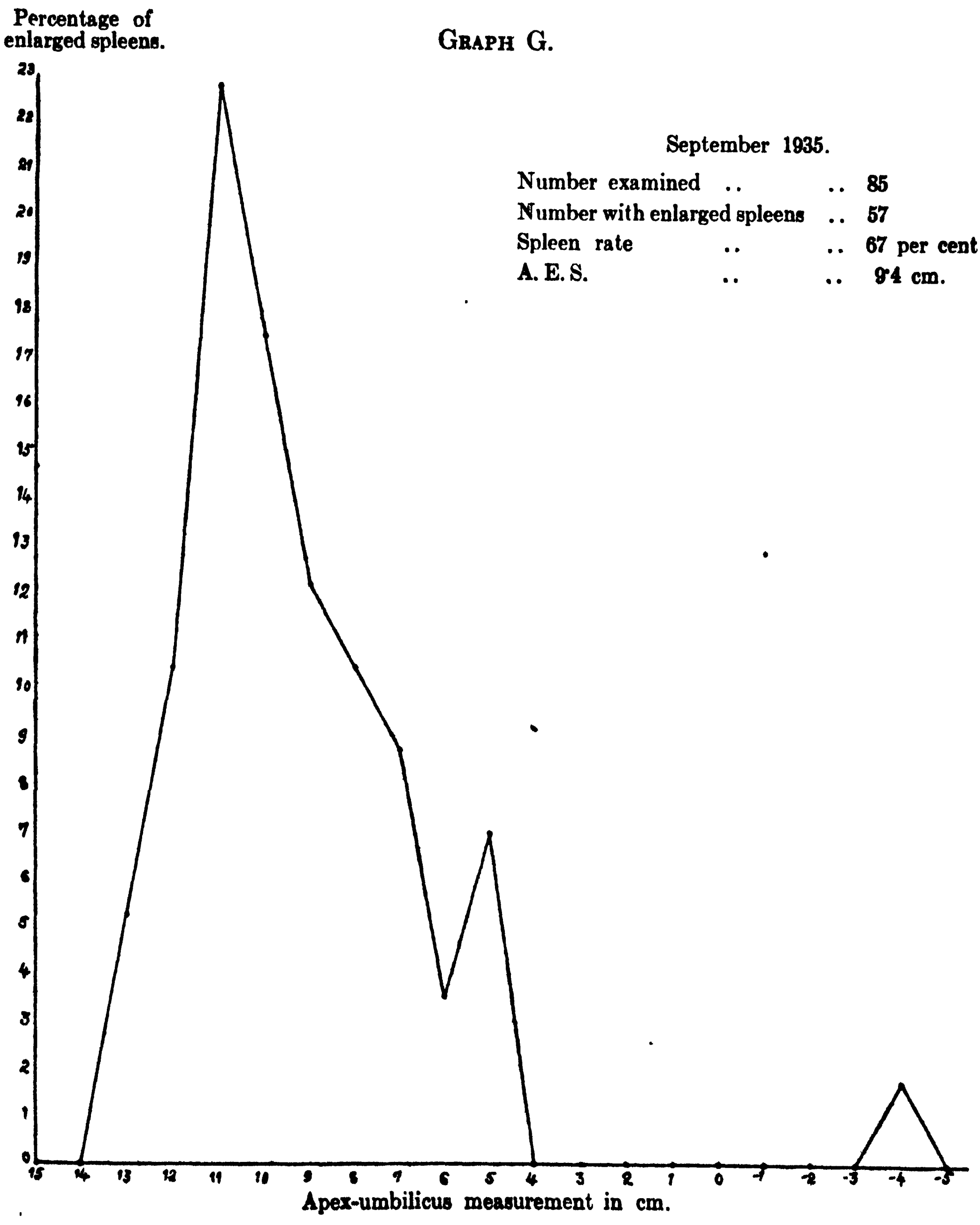
The railway quarters are situated immediately to the west of the railway yard and lie on the eastern boundary of the Group B area (*vide* Map). In May 1935, 88 children were examined in this locality among whom the spleen rate was found to be 38 per cent, and the average enlarged spleen 9 2 cm. These findings indicate a degree of malarial incidence intermediate between that observed in Group B and Group E for the same season. This is not surprising as the railway quarters are situated about midway between the centres of the two latter groups. Local inquiries showed that many of the children living in the railway quarters had been resident there for a number of years, while others had arrived in Quetta more recently. Malaria control measures had been in force within the precincts of the railway territory prior to the earthquake, but it is probable that much of the malaria transmission was connected with causes lying outside the jurisdiction of the railway authorities. The railway population also has easy access to quinine treatment and, so far as could be ascertained, advantage is taken of this facility. Taking these factors into consideration, it seems probable that the railway quarters are located on an even more unhealthy site than the figures indicate at first sight. Numerous dangerous anopheline breeding-places are present in close proximity. Owing to the destruction of the houses in this locality following the earthquake, and the subsequent dislocation of the population, it was not possible to repeat these examinations later in the season.

(*ii*) *Hudda and Habib villages.*

The population of the Hudda and Habib villages is well known to be a floating one. For this reason no spleen examinations were made in these villages prior to the earthquake, and for the same reason these villages were not included in the Group B area although they are territorially situated within the latter area. No reliable estimate could be made of the probable average duration of residence of the inhabitants in these villages.

In September 1935, the spleen rate among 85 children examined in these two villages was found to be 67 per cent, and the average enlarged spleen 9·4 cm. Some of the anopheline breeding-places in the immediate vicinity of these villages were controlled during the malaria season, while others were not. During the course of the survey numerous infected mosquitoes were collected from Hudda.

GRAPH G.



The frequency distribution of the average enlarged spleens in the Hudda-Habib area is shown in Graph G from which it will be seen that the mode occurred at 11 cm. The high proportion of small spleens suggests that many of the infections were recently acquired ones. Little can be said regarding the probable nature and amount of malaria in these villages under ordinary conditions. During the malaria season of 1935 malaria was very prevalent, and, as has been said, it is probable that many of the infections had been recently acquired.

3. SEASONAL DISTRIBUTION OF MALARIA IN QUETTA.

(*a*) THE CASE INCIDENCE OF MALARIA.

The malaria season in Quetta is a short one and occurs usually in August, September and October. Examination of the figures given by Molony and Gorman (1936) shows that, among the troops, there is a well defined increase in the number of malaria cases admitted to hospital during these months. The maximum number of admissions for malaria usually occurs either in August or September according to the year. The admissions to military hospitals for malaria for the year 1935 (the year under review) are shown in Table XXIV.

TABLE XXIV*.

Showing the monthly admissions for malaria to military hospitals in Quetta for 1935.

Actual numbers admitted.†	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Total.
British Military Hospital.	2	2	1	4	10	5	23	189	150	13	2	1	402
Indian Military Hospital.	12	6	13	23	36	28	75	421	417	132	37	12	1,212
TOTAL ..	14	8	14	27	46	33	98	610	567	145	39	13	1,614

* The figures given in this Table have been supplied to us through the kindness of Lieut.-Colonel J. B. de W. Molony, O.B.E., I.M.S.

† Including 'relapse cases' and fresh infections.

It will be observed that while a relatively small number of malaria cases was admitted to the military hospitals in Quetta throughout the greater part of the year, the admissions for malaria were greatly increased between July and October, particularly in August and September. Allowing for an incubation period of about 2 to 3 weeks, it will be observed that the season of highest case incidence corresponds almost exactly with the period of greatest infectivity in the anopheline population. It seems probable from our observations that the season of active malaria transmission in Quetta is a very restricted one (probably from 2 to 3 months), and that the cases occurring at other seasons of the year are due either to relapses or to protracted incubation periods. The latter have been shown by recent experimental work to be much commoner than was formerly suspected.

Although no extensive blood examinations were made in the local civilian population, the marked increase in the spleen rate which was observed in some localities within a comparatively short period is confirmatory evidence of the military figures quoted above. In some villages a striking increase in the spleen rate was observed between the spleen census taken in May and that taken in September, while in others a similar marked increase was observed between the spleen rates observed early in August and those observed late in September.

There is, therefore, a considerable amount of evidence to show that the transmission of malaria in Quetta is restricted to a short period of the year and probably occurs mostly in July, August and September. This is important in relation to the period during which it would be necessary to undertake anti-malaria measures.

(*b*) Meteorological conditions in relation to the seasonal incidence of malaria in Quetta.

Judged on the standards generally accepted for northern India, the period during which temperature and relative humidity are favourable for malaria transmission in Quetta is a very short one. But as has already been pointed out the fact that the chief malaria-carrying anopheline is a Mediterranean species which apparently selects suitable 'micro-climates' in which to shelter, makes it inadvisable to place too much emphasis on the general conditions of temperature and humidity in Quetta. It is probable, however, that the latter are suitable for malaria transmission for continuous periods varying from about 6 to about 10 weeks in the year. This estimate is based on the figures available for the last ten years. During this decade more than usually severe exacerbations of malaria occurred in 1926, 1933 and 1935. In each of these three years the relative humidity was in the vicinity of 60 per cent for a continuous period of about 9 weeks, whereas this period did not exceed 6 or 7 weeks in the other years. The mean temperature for all years was over 60°F. during the period when the relative humidity was approximately 60 per cent or over.

No official meteorological figures were available for Quetta during the malaria season of 1935, but rough figures were obtained from two improvised meteorological stations maintained by the malaria survey party. One of these was erected in the Civil Lines near Sandeman Hall and the other near the Race Course Grand Stand. The relative humidity in the latter was appreciably higher than in the former, and this may possibly be explained by the greater prevalence of trees, surface water, etc., near the Race Course station.

A point of particular interest in regard to malaria in Quetta is the relationship between rainfall and malaria incidence. In a statistical analysis of the figures for the past 47 years, Molony and Gorman (1936) found no correlation between malaria incidence and total annual rainfall. During 1935 active malaria transmission was undoubtedly going on during August and September even though there was no rainfall between April and October of this year.

The influence of rainfall is probably dependent more upon its distribution than upon the total amount. Heavy winter and spring rainfall probably influences the incidence of malaria in the ensuing season by increasing the yield of individual springs, or, as in the present year, by increasing the actual number of springs. Heavy rainfall occurring during the malaria season might be expected to exert both favourable and unfavourable influences. Thus heavy

falls, whether local or distant (as in the adjoining hills), would probably have beneficial results by their action in flushing out rivers, streams and nullahs. On the other hand such rainfall might be responsible for the creation of temporary breeding-grounds, and for conditions of relative humidity more favourable for the longevity of mosquitoes. The latter occurrence might allow of the Oriental species of mosquitoes such as *A. culicifacies* and *A. stephensi* playing a relatively greater part in the transmission of malaria in Quetta in certain years.

V. THE IMPORTANCE OF MALARIA IN RELATION TO THE RECONSTRUCTION OF QUETTA.

1. THE CHOICE OF HEALTHY SITES.

It will be clear from the above considerations that Quetta is situated in a valley in which the incidence of malaria is as high as that which occurs in almost any part of India. This being the case, it cannot be admitted that, from the malaria point of view, the site of Quetta is a satisfactory one. It is understood, however, that the maintenance of a large garrison in this locality is considered to be imperative. It may therefore be confidently anticipated that a large civil population will again grow up in close proximity to the military station. The problem with which we are faced thus becomes a matter of what steps can be taken to minimise the malarial incidence among this civil and military population.

In our opinion, the future health and prosperity of Quetta will depend largely on its relative freedom from malaria. Evidence is not wanting that the intensity of malaria in this locality varies considerably in places at no great distance apart, and there is every reason to believe that the best chance of reconstructing a comparatively healthy Quetta lies in the selection of the least malarious localities on which to rebuild. The extreme importance of choosing healthy sites for human habitations in the tropics was first emphasised by Christophers and Stephens (1901) in Africa. Watson (1921) records several examples of the immense improvement in the health of certain sections of the population in Malaya when unhealthy sites were abandoned and others, sometimes only a short distance away, were chosen to replace them. In a recent paper the same author (Watson, 1936) again emphasises the extreme importance of siting as an anti-malaria measure. Deeks (1930) in America also stresses the importance of this measure.

It is a matter of good fortune that both the cantonment and the city of Quetta were originally founded on sites which were probably as healthy as, and possibly healthier than, many others in the surrounding valley. In more recent years, the need for expansion which arose from the ever-increasing population, resulted in the occupation of less healthy localities. The wholesale destruction of the houses in the greater part of Quetta has created a situation which seems to offer an unparalleled opportunity for avoiding a repetition of expansion on unwholesome sites, and of planning the new Quetta in such a way that the suffering and economic losses associated with a high incidence of malaria will, in the future, be reduced to a minimum. *It cannot be too strongly urged that the selection of sites which are relatively free from malaria, or which can be made so cheaply and easily, is an anti-malarial measure of fundamental importance, and that every advantage should be taken of this measure during the reconstruction of Quetta.*

In making detailed recommendations regarding the most suitable sites for the reconstruction of Quetta several factors have been taken into consideration. In the first place due regard has had to be given to previously existing vested interests. Fortunately the sites recommended coincide in many cases with the greatest vested interests. There are, however, exceptions to this rule, the chief of which are those connected with the railway and the Royal Air Force. Secondly, it has been our aim to advocate expansion or reconstruction on sites which are relatively free from malaria, and in which there appears to be no necessity for highly expensive anti-malarial operations. Thirdly, where anti-malarial works appear to be essential, every endeavour has been made to recommend those sites where these operations could be most easily effected, and carried out at the lowest cost.

The recommendations which have been made are limited to the consideration of the health of the garrison, the municipality, and the various Government departments which form Quetta. The amelioration of malaria in a large, compact community such as this is not only feasible, but will be found to be a paying proposition. No consideration has been given to the mitigation of the malaria scourge in the villages in the surrounding area. In our present state of knowledge, save under very exceptional circumstances, no method of malaria control by mosquito destruction has so far been devised, which is sufficiently cheap to be *within the financial resources* of most small isolated villages in India. The only procedure which appears to be applicable to these unfortunate cultivators is a programme of quininisation to reduce the morbidity and mortality from malaria. In this respect the villagers of Baluchistan share the fate of their brethren in the rural districts of most parts of India.

2. DETAILED CONSIDERATIONS REGARDING SITES FOR THE RECONSTRUCTION OF QUETTA.

Roughly speaking, the Quetta area is divided from north to south by the railway line, and from east to west by the Habib nullah. These intersections serve to divide Quetta and its immediate environs into four distinct areas, a division which will facilitate reference and description (*vide* accompanying map) :—

(*a*) Cantonments lie east of the railway line and north of the Habib nullah.

(*b*) Quetta city and civil lines are situated east of the railway line and south of the Habib nullah.

(*c*) West of the railway line and south of the Habib nullah the police lines and a large part of the railway colony are situated, and also the villages of Hudda-Habib, which, it is understood, may be incorporated within the municipality of Quetta in future.

(*d*) West of the railway line and north of the Habib nullah lie the Royal Air Force lines and the Quetta jail.

These four areas vary considerably in their salubrity from the malaria point of view. The incidence of malaria among personnel residing in one area may, however, be considerably affected by the conditions prevailing in another. A more detailed consideration of these four areas is given below :—

(*a*) QUETTA CANTONMENT.

The land which lies within the present cantonment boundary is, for the most part, high, dry and porous, and slopes in a westerly direction with an

average gradient of over 100 feet per mile. Owing to the complete absence of natural water outcrops, and to the relative scarcity of irrigation water, this area is probably one of the least malarious tracts in the Quetta valley. Such mosquito-breeding places as exist within the cantonment boundary are chiefly man-made and are therefore capable of control. Irrigation water is derived mainly from the Hanna river, and this is supplemented by a few karezes, the chief of which are the Sahibzada kareze originating in the lower part of the Hanna valley, and the Lal Khan kareze which enters the station in the vicinity of Jacob lines. The only other watercourses of note in this area are the Habib and Durani nullahs. *Provided* that irrigation water is properly controlled and distributed and that permanent water channels are properly constructed and maintained, there is little to fear from mosquito-breeding within the cantonment limits, under existing conditions*. Adequate anti-malaria sanitation would, of course, have to be properly supervised and maintained.

The chief sources of malaria in cantonments lie outside the cantonment boundary. The bulk of the malaria which occurs among the troops appears to be contracted in lines situated at the periphery of the station and especially in those which are in close proximity to known foci of high malarial incidence. Once infected these lines in their turn become a source of danger to their neighbours. The units situated on the north-west periphery of cantonments (Ammunition Depôt, Mansfield lines, Campbell barracks, etc.) account for a large number of the malaria cases occurring annually in cantonments, whereas those situated east of Kings Road are comparatively free. The high incidence of malaria among the former units is attributable to their close proximity to the Kotwal-Navagaon group of villages which are situated just outside the cantonment boundary. Between these villages and the military lines there are extensive anopheline breeding-grounds which are derived from the Navagaon irrigation channels (Hanna river supply), and the Kotwal kareze which originates in cantonments.* This area is undoubtedly the most dangerous focus of infection in the vicinity of Quetta cantonment, and is probably responsible, directly and indirectly, for the majority of the malaria infections contracted within cantonments.

(i) *The acquisition of the Kotwal-Navagaon area.*

We understand that a proposal is under consideration for the acquisition of a tract of land some 2,500 yards square embracing the present site of the Kotwal-Navagaon group of villages. This land would be used as a site for cavalry lines. This proposal raises a question of paramount importance to the health of Quetta cantonment.

Provided that this area were acquired by the military authorities together with the complete water rights of the Kotwal kareze and the Navagaon irrigation stream (from Hanna river), and that *these irrigation supplies were entirely suspended,* the incidence of malaria among the troops in the neighbouring lines would, in all probability, be reduced to unimportant proportions, and the chief source of malarial infection to the cantonment would be eradicated. The fate

* In making this statement we wish to point out that this state of affairs might be reversed if additional irrigation supplies become available within this area. We have had no opportunity of estimating the effects of rain-water collections in borrow-pits and other depressions within cantonment limits. The latter could be conveniently filled up with debris from buildings destroyed during the earthquake.

of the troops occupying the new site would, however, be less certain. A careful study of this tract of land and its environs has been made, and we are of opinion that, if properly arranged, lines constructed within the newly acquired area would be at least as healthy as, and probably much more so than, those at present situated near the cantonment boundary in this vicinity.

The incidence of malaria in the new cavalry lines would be dependent to a considerable extent on the location of the animal lines and barracks within the newly acquired area, and upon the fate of the water channels mentioned above. From the malaria point of view the best procedure would be to erect the men's quarters as near as possible to the present cantonment boundary as far east as possible and to interpose a protective barrier between these quarters and neighbouring infected villages. This protective barrier would take the form of the horse lines and followers' quarters. The military veterinary hospital, if constructed in this area, could also, with advantage, be similarly utilised. Animal lines thus situated would serve as an attraction for anopheline mosquitoes tending to infiltrate into the area from outside. Large numbers of these, including many which would probably be infected, could then be destroyed by insecticidal sprays used at regular short intervals in the animal lines.

From inquiries made locally it has been ascertained that the villages of Tarin and Kili Gul Mohamed are entitled to a very small proportion of the water supply from the Kotwal kareze and the Navagaon irrigation stream. It is suggested that compensatory water might be given to these villages from the piped water supply. The construction of pipe lines or alternate irrigation channels to these villages would do much to prevent mosquito-breeding in the immediate vicinity of the newly acquired area.

(ii) Other possible sites for expansion of cantonments.

Special attention was directed to unbuilt tracts of land lying within, or immediately adjacent to, the present cantonment limits, with a view to determining whether these would be likely to be malarious or not.

In our opinion one of the sites which would be most free from malaria lies in the angle between Kings Road and Hanna Road. This area is high and dry and is far removed from any natural water outcrops. This is potentially one of the least malarious tracts in the vicinity of Quetta, but we are informed that there are objections to building here from the military point of view.

Another tract of land within cantonment limits which appears to be relatively healthy from the malaria point of view is bounded on the east by Pioneer Road, on the north by Queens Road, and on the west by the light railway running to the litter dump. At present this area is under cultivation. We are informed that after heavy rainfall this area becomes flooded by storm water from the adjacent hills, but that this flooding would be easily preventible by diverting the storm water in the vicinity of Jacob lines by means of a bund. It has been suggested that this area should be reserved for the site of the military dairy farm which is at present situated near the centre of the cantonment. This suggestion appears to us to be a good one, inasmuch as it would entail (*a*) complete control of the irrigation of this land by responsible military authorities, and (*b*) offer an opportunity for interposing the animal lines between the municipal and cantonment areas. These lines would act as a

mosquito-trap in a manner similar to that indicated in the case of the proposed new cavalry lines. On the same principle as in the latter case the animal houses would be constructed on the side next to the municipal area, with the living quarters as far removed from them as possible.

Another line of expansion for cantonments which might be considered, would be the land lying to the north of cantonments and at present occupied by the rifle ranges. From the malaria point of view this site would be considered healthy only if the Kotwal-Navagaon area were taken over and controlled. So long as the latter remains in its present condition any lines situated in this vicinity would be expected to show a high incidence of malaria.

The more central parts of Quetta cantonment are regarded as relatively non-malarious, and most of the malaria which is contracted here is probably attributable to purely local causes which should be easily dealt with in the course of ordinary anti-malaria sanitation.

Owing to the very highly malarious nature of much of the surrounding country, troops occupying camp sites in the neighbourhood during the months of July, August and September especially, would be very liable to get infected with malaria.

(b) Quetta Municipality and Civil Lines.

The area occupied by Quetta city and the civil lines is situated east of the railway line and south of the Habib nullah. Compared with much of the country in the vicinity, this area may be regarded as a relatively healthy site from the malaria point of view. A portion of the railway colony also lies within this area and includes the residential quarters of the superior personnel.

(i) *Quetta city.*—It appears to us that some difficulty would be experienced in selecting a less malarious site for the new Quetta city than that which is occupied by the ruins of the old city. From the malaria point of view, a city rebuilt on the old site should be a fairly healthy one, provided that proper precautions be exercised. These precautions would include the filling up of all adjacent depressions and excavations with debris from the ruined city, the closure of all kareze and irrigation channels within municipal limits, and the provision of an adequate piped water supply sufficient for all domestic purposes and for such other purposes as street watering, flushing, and irrigation of gardens. We wish to stress here that, during the progress of reconstruction, great care should be exercised to avoid the creation of fresh dangers in the form of brick-fields, borrow-pits, etc., in the vicinity. Such excavations should not be permitted within three miles of the periphery of the new city or cantonments.

It seems probable that, on account of the liability to earthquake, new buildings in Quetta will be restricted to a single storey. Assuming that the city will eventually regain its former population, or even exceed it, it is evident that the total area occupied will be larger than formerly if such buildings be erected. From the point of view of malaria prevention the best line of expansion would appear to be in a south-easterly direction towards Volunteer Point between Barnes Road and Quarry Road. Expansion in this direction could safely be continued right up to the foot of the hills as far as the rifle ranges.

Much of the land in this area has been extensively excavated in connection with brick-making. In many places it would appear to be feasible to make this land suitable for building by reducing large areas to the level of the bottom

of these extensive excavations, while in other areas filling with debris from the city could be undertaken. 'Gwalmandis' should be situated at the periphery of the area of expansion in such a way as to obviate their inclusion within the city as expansion proceeds.

We understand that, prior to the earthquake, a proposal was under consideration for the inclusion within the municipality of the Hudda-Habib area, which is situated west of the railway line in the vicinity of the Habib nullah. This proposal would appear to indicate a tendency for the expansion of Quetta municipality west of the railway line and south of the Habib nullah, a procedure which would, in our opinion, eventually lead to the growth of a highly malarious community in this locality. The permanent control of malaria in this area would be a difficult and highly expensive undertaking. We strongly recommend, therefore, that, since this community is at present homeless, every effort should be made to induce the inhabitants of these villages to rebuild within the municipality, on sites within, or contiguous to Quetta city, expanding, if necessary, in the direction indicated above, *i.e.*, in the direction of Volunteer Point and east of Quarry Road.

(*ii*) *Civil lines.*—The civil lines are situated on a narrow strip of territory extending roughly from Lytton Road to the railway. The sources of danger from malaria occurring within this area are not numerous, and are easily controllable. The chief sources of danger to this community lie in the country west of the railway, where the control of mosquito-breeding areas is somewhat more difficult.

Provided that proper anti-malarial sanitation is carried out within this area, and that the various residences are properly mosquito-proofed, there would be every reason to expect that this area should be fairly healthy from the malaria point of view. The danger of acquiring malarial infection is reduced considerably by the fact that comparatively few families are resident in this area, and that, of these, a goodly proportion move to Ziarat for the most malarious months.

A point of particular importance to this community is the presence of the Civil Hospital in its midst. During the malaria season many of the patients in hospital suffer from malaria, and are a source of danger to the neighbouring residents. This makes it imperative that the hospital wards should be effectively mosquito-proofed.

Any anti-malarial measures directed towards the control of malaria in the railway colony and the vicinity of the Race Course would have a beneficial effect on the civil lines. The abolition of the Hudda-Habib colony from its present site would also have a beneficial effect.

The above remarks apply equally to the residential part of the railway colony which lies immediately to the south of the civil lines. The proximity of the former to the unhealthy sites occupied by the subordinate and menial personnel of the railway, makes the conditions here less favourable than in the civil lines.

(*c*) The Railway Colony and Police Lines Area.

As has been pointed out above, that part of Quetta which is situated east of the railway line may be regarded as relatively non-malarious, except in those parts in which the control of irrigation water has been completely neglected. West of the railway line this state of affairs is reversed. The railway line runs roughly parallel to the Lora stream and about a mile east of it. It is probable,

therefore, that the intense mosquito-breeding which occurs in the Lora exerts a considerable influence on the malarial incidence among the population resident west of the railway. While this is true it is not, unfortunately, the only, or even the chief, source of malaria in this area, at least in that part which is situated south of the Habib nullah. Commencing in the vicinity of the railway quarters and police lines and proceeding westwards towards the Lora stream, one encounters an increasing number of natural springs and seepages all of which are most dangerous breeding-places, and are probably a greater source of malaria among the communities resident in this area than the Lora stream itself.

This locality, besides being very highly malarious, has the great disadvantage that to eradicate malaria would be a very difficult and expensive undertaking. Any scheme for the permanent control of malaria in this area would, in our opinion, involve some planned system for the collection and redistribution of irrigation water which would entail the abolition of the nuisance at present arising from natural water outcrops, and the control of the Lora stream and the innumerable seepages which occur in its vicinity. Such a scheme could only be drawn up in collaboration with an expert engineer and would undoubtedly be an extremely expensive undertaking. The senior author had the opportunity, while in Quetta, of visiting this area in company with Mr. Oddin Taylor, Chief Engineer, Baluchistan. Mr. Taylor offered the tentative opinion that the springs in this area are artesian in nature. Owing to the nature of the country, and of the soil, he did not think that any ordinary drainage scheme would be satisfactory, but suggested that good results might possibly be attained by sinking a large series of tube or artesian wells thereby preventing the water from finding its own outlet at the surface. Water thus removed could be collected and properly distributed for irrigation purposes. During the present malaria season, this area has been admirably controlled by Major C. M. Nicol, I.M.S., Chief Health Officer, Quetta, by temporary measures such as canalisation, oil and Paris green. No matter how well carried out, temporary measures of this kind are not entirely satisfactory. Besides involving a high recurrent expenditure, the success of such measures is dependent mainly upon the ability and enthusiasm of the supervising officer, and the co-operation of the zamindars. The latter is likely to be wanting, as the application of larvicides is already unpopular. The occurrence of heavy rainfall during the malaria season would do much to render temporary measures abortive, and the comparative success of the undertaking during the present season has been largely attributable to the complete absence of rainfall during the malaria season. The likelihood of a municipality such as Quetta being able and willing to meet the high recurrent cost of maintaining a health officer and staff, approximating in efficiency to that operating in Quetta this year, seems to us to be remote. Any programme of malaria control which is entirely, and continuously, dependent upon the human factor is almost certain to break down sooner or later, with disastrous results. Numerous examples of this have not been wanting in the past.

In view of these considerations we strongly advise that no extension of Quetta municipality should be contemplated in this area, and that the growth of uncontrolled villages such as Hudda should, as far as possible, be prevented. Such communities are likely ultimately to be incorporated within the municipality as has been suggested in the case of the Hudda-Habib area at present. The

growth of unhealthy populations in the immediate vicinity of Quetta must inevitably have repercussions on the health of both the civil and military population. Hudda has been regarded as the starting point of most epidemic diseases with which Quetta has been afflicted in more recent years.

Turning now to the integral parts of Quetta which have the misfortune to be located in this area, it is necessary to consider the future of the railway colony, and of the police lines.

(*i*) *The police lines.*—For many years past the police force occupying the Beaty police lines has been very highly infected with malaria. Exact figures showing the incidence of malaria among this force were procured by the senior author, but were unfortunately lost in the earthquake. The site of the police lines is not a large one, but it is a most insalubrious one. Protection of this site, as has been indicated above, would be a difficult and expensive undertaking. It is therefore recommended that a less malarious site be acquired for these lines. We know of no reason which makes it imperative to retain the present site. No great difficulty should be experienced in obtaining a small but healthy site near the civil lines and east of the railway line.

(*ii*) *The railway colony.*—The railway area in Quetta lies partly to the east of the railway line and partly to the west of it. In the former situation most of the residential quarters of the superior railway staff are located, while in the latter the quarters are mostly those of the subordinate and menial personnel.

The railway quarters west of the railway line and lying immediately to the south of the Beaty police lines occupy a malarious site. The ideal solution of this problem would be to acquire a healthy site for these quarters, and to transport the employees to and from their work. It is learnt, however, that it is considered to be obligatory that the railway personnel should reside on the spot, and that the vested interests in the railway yard and the absence of suitable gradients elsewhere, make it imperative that the railway colony must remain in its present vicinity. We are informed that it is proposed to acquire a strip of land adjoining Joint Road, and lying immediately south of Brewery Road, which will join the present railway holdings on Brewery Road and those west of the Sariab railway crossing. This strip of land is probably as healthy as any in this locality, but cannot be regarded as an ideal site for building. Since the railway area includes land on both sides of the railway track it is recommended that, as far as possible, living quarters be constructed on the east side of the tracks, and that the land to the west of the tracks be utilised, as far as is practicable, for non-resident buildings such as stores, godowns, offices, etc., and for recreation grounds. Such residential quarters as may have to be constructed within these limits should be situated as far away from the Beaty police lines as possible. Mosquito-proofing of any such quarters would be most beneficial. Unless extensive and probably expensive anti-malarial measures are instituted within as well as outside this area, it cannot be confidently anticipated that any new residential quarters situated west of the railway line will be healthy from the malaria point of view.

(*d*) The Royal Air Force Lines and the Jail.

We come now to the consideration of that part of Quetta which lies west of the railway line and north of the Habib nullah. The influence of the Lora stream on this area is much the same as that described for the corresponding

area south of the Habib nullah. On the other hand this area is free from the numerous natural water outcrops which are so great a danger south of the Habib nullah. There are, however, a number of open kareze channels situated within this area which are extensive breeding-grounds for dangerous anopheline mosquitoes. The only two integral parts of Quetta with which we are concerned in this area are the R. A. F. Lines and the Jail. In both instances the factors influencing the incidence of malaria are probably more intimately connected with the area considered in connection with the police lines area, than with factors arising within the area now under consideration.

(*i*) *Royal Air Force Lines.*—The present site of the R. A. F. Lines is a malarious one, as is indicated by the high incidence of malaria which has been known to occur among the R. A. F. personnel in recent years. The reason for the unhealthiness of this site is to be found in its proximity to the numerous dangerous breeding-places lying in the vicinity of Hudda, and extending from this area towards Woodcock Spinney and beyond it, in the direction of the highly malarious villages of Abdullah Jan and Kili Sultan. We are informed that the site of the present aerodrome is the only suitable one available, and that the R. A. F. personnel *must* be quartered in *close* proximity to the aerodrome. The choice of sites is, therefore, very limited. In our opinion the least malarious site in this vicinity would be that which is at present occupied by the village of Kili Ismail. When examined by the senior author in May 1935, the spleen rate in this village was lower than in any other village in the vicinity of Quetta (11 per cent). The construction of the new R. A. F. Lines in this situation would, we feel confident, be a great improvement on the present site which is on the edge of the Durani nullah, and at no great distance from Hudda village. This suggested site, although by no means an ideal one, should prove tolerably healthy if the new living quarters are properly mosquito-proofed, and ordinary measures for malaria control are carried out.

(*ii*) *The Quetta Jail.*—The old site of the jail was in close proximity to the R. A. F. Lines and, like the latter, was a malarious one. As the area occupied by the jail site is a very small one, and as its location is apparently not determined by any attachments as in the case of the railway and R. A. F. quarters, it is suggested that a new site should be chosen for it somewhere east of the railway line. Proximity of the jail to any new site selected for the police lines would, presumably, be an advantage in administration.

VI. THE FUTURE OF MALARIA IN QUETTA.

1. SPECIAL PRECAUTIONARY MEASURES.

At the present time when Quetta is virtually a collection of ruins and condemned buildings, and when no definite decisions have, so far as we are aware, been made with regard to the details of the reconstruction programme, it is obviously impossible to do more than outline the general principles which should be followed in regard to the future control of malaria in Quetta. It will be necessary for the men on the spot to adapt these principles to meet conditions as they arise.

It must be admitted that our present knowledge of the malaria problem in Quetta is based almost exclusively on observations made during a single season, and that the interpretation of these observations cannot be regarded as conclusive. It has frequently been remarked in the course of this report that many

of the deductions made require confirmation, and that this can only be done by repeating and extending the survey work which was commenced in 1935. Even in the absence of fuller and more exact information on this subject we do, however, feel justified in formulating certain generalised proposals which, if acted upon, will, we feel sure, do much to reduce the incidence of malaria in Quetta. These proposals are based on the assumption that it is intended to restore Quetta approximately to its former proportions, and to reconstruct it as far as possible on its original site.

(*a*) THE CHOICE OF SITES FOR RECONSTRUCTION.

Detailed recommendations have already been made regarding the choice of relatively healthy sites for the reconstruction of Quetta. The taking of appropriate action on these recommendations appears to us to be the most important fundamental step towards the reduction of malaria in the new Quetta. It cannot be claimed that the sites suggested are ideal ones, but they are probably as suitable as any which are available in this locality. In some instances, particularly in the case of the railway quarters and the Royal Air Force lines, it cannot be confidently anticipated that the sites selected will be healthy ones, and they have only been suggested as a compromise between health and vested interests. We are not prepared to admit that this compromise is advisable, but, for the reasons cited above, no alternative was open to us.

(*b*) REMOVAL OF SOURCES OF HUMAN INFECTION.

The close proximity of highly malarious villages is a source of great danger to the inhabitants of Quetta. It is, therefore, very desirable that, wherever possible, such villages should be removed. For this reason it would be highly beneficial to the adjacent parts of Quetta if the Hudda-Habib colony could be removed from its present site to a less malarious one. Similarly the acquisition of the Kotwal-Navagaon area by the military authorities, and the eradication of these villages, would do much to reduce the source of malaria infection for the inhabitants of the neighbouring parts of the cantonment.

It is equally important that the growth of new colonies which are likely to be a menace to the future health of Quetta should be prevented. The truth of this is well exemplified by the growth of the Hudda-Habib colony which, in recent years, has been regarded as the starting point of most epidemic diseases which have broken out in Quetta.

Where the removal of highly malarious communities to healthier or more distant sites is impracticable, steps should be taken to ensure that such communities are adequately treated with anti-malarial drugs. The adoption of a programme of mass quininisation of such communities will be the burden of the civil administration, and has more to commend it than the motive of self-preservation.

(*c*) THE ERADICATION OR CONTROL OF MOSQUITO-BREEDING PLACES.

(*i*) *Limitation and control of irrigation.*—Under the conditions prevailing at the present time, the relative scarcity of irrigation water within the limits of Quetta serves automatically to minimise the number of dangerous mosquito-breeding places arising from this source. If, under the proposed new Spin-kareze project, the irrigation supplies for use within the Quetta area be greatly

increased it may confidently be expected that the incidence of malaria will show a proportionate increase. *Every effort should be made to restrict the amount of irrigation water admitted to Quetta to the barest minimum commensurate with actual requirements, and to control its distribution in such a way as to prevent mosquito-breeding.* The moment irrigation water ceases to be a precious and jealously guarded commodity, the incidence of malaria may be expected to show an alarming increase. The fact that the neighbouring military station of Fort Sandeman heads the list of the most malarious cantonments in India is largely due, in our opinion, to the admittance to this station of irrigation water in excess of actual requirements. So far as we are able to judge, the epidemiology of malaria in these two stations is not very dissimilar, and if Quetta is to escape the unenviable reputation of Fort Sandeman, the limitation and control of irrigation water deserves careful attention. The time to emphasise the dangers arising from over-irrigation, particularly in the north-west of India, is before expensive irrigation schemes are inaugurated, because once these expensive undertakings have materialised, the mitigation of the evils which follow will become a matter of compromise between health and vested interests in which the former is likely to receive but scant consideration.

The control of irrigation outside the limits of the cantonment and the municipal area of Quetta is a more difficult problem. Temporary measures, besides being the source of recurrent expenditure, are likely to be opposed by the local inhabitants, and for this reason it is important to make a careful selection of sites and to contemplate the acquisition of land. In the vicinity of the Kotwal-Navagaon villages, for example, irrigation may be said to have 'run riot' in close proximity to barracks occupied by troops. The acquisition of this area by the military authorities appears to us to be the only means of bringing this atrocious state of affairs completely under control.

(*ii*) *Acquisition of land.*—The acquisition of certain tracts of land is very important in regard to the future control of malaria in Quetta. This procedure has been advocated in certain instances, in order to obtain, (*a*) healthy sites for expansion, (*b*) the eradication of foci of high malaria infection, and (*c*) the abolition of dangerous mosquito-breeding places arising from uncontrolled irrigation.

(*iii*) *Reclamation of land.*—In the vicinity of Quetta there are numerous excavations and depressions, including brick-fields and borrow-pits, which are potential sources of danger from the malaria standpoint. Much good could be accomplished by filling up such places with the debris from the ruined city. In those areas where excavations have been made on a very large scale, it is suggested that reclamation could best be effected by levelling the surrounding territory flush with the bed of the excavations. Besides removing potentially dangerous mosquito-breeding places, land reclaimed in this way would be transformed into healthy sites for reconstruction. This is particularly true of the much excavated tract of land lying between the former site of the city and Volunteer Point, *i.e.*, the area to the south-east of Quetta city.

It is imperative that the creation of fresh dangers of this kind (brick-fields, borrow-pits, etc.) should be prohibited during the reconstruction of Quetta. As has been pointed out above, no excavations should be permitted within three miles of the outskirts of the new Quetta. Omission to enforce this precaution will eventually lead to the expenditure of much larger sums of

PLATE III.

Fig 1 The Hanna river Note the network of shallow streams flowing over a stony bed

Fig. 2. The Hanna valley. A rapidly-flowing irrigation channel (left), leakage from which has given rise to a shallow marshy area in which the current is slow (right).

PLATE IV.

Fig 3 The Lora stream Note the bed of the stream lying between high banks and rich in grassy vegetation

Fig 4 The Lora stream. Note the single channel which is largely devoid of grassy vegetation, and the numerous seepage channels on the steep banks

PLATE V.

Fig 5 A kareze channel partially underground and partially exposed to direct sunlight Anopheline breeding is observed where green vegetation occurs Adult anophelines are found resting in such places by day

Fig 6 The Habib nullah containing the outflow of the Kizi kareze Anopheline breeding was intense at the point shown Note the ruins of houses destroyed during the earthquake

PLATE VI.

Fig 7 The outflow of the Balkh spring Note the accumulation of seepage water to the left of the channel

Fig 8 Excavations containing water No anopheline breeding was observed here in May 1935, and when visited in August the water had disappeared Filling up of such excavations with debris from the ruined city has been recommended

money than would be incurred in the prevention of this nuisance during reconstruction.

2. MALARIA SANITATION IN QUETTA.

No matter what steps may be taken during the period of reconstruction to ameliorate malaria in Quetta, it cannot be foreseen that it will be possible in the future to neglect ordinary measures of malaria sanitation. It has already been pointed out that the incidence of malaria among one section of the community in Quetta may be attributable to causes lying outside the territorial jurisdiction of that community. It is therefore obvious that if any scheme for malaria sanitation is to offer any hope of success, the closest co-operation between the various administrations operative within the Quetta area must be obtained.

The best chance of obtaining this desirable state of affairs appears to us to lie in the formation of a strong Malaria Committee, the members of which would be responsible representatives of the various administrations which collectively form Quetta. It must be realised that the health of the community is the responsibility of these administrations and not that of their technical advisers. Such a committee was in existence just before the earthquake, and good progress was being made, especially in the direction of making the public 'malaria conscious'. In the municipal area much was achieved by citizen effort, but there is a limit to the extent to which responsibility can be shifted from government to individual. In Quetta the stimulus for the citizen health campaign undoubtedly originated through the efforts of a high government official, and although the results never attained fulfilment, there is an excellent precedent for future work on these lines. It may be found necessary, in the future, for the Malaria Committee to maintain the services of an anti-malarial officer and a properly trained staff to work under him.

Further investigation on the epidemiology of malaria in Quetta will greatly facilitate the effective working of malaria control measures. This report is based on observations made during a single season, and it is not unlikely that conditions may vary considerably in different years. The investigation of the malaria problem in Quetta still requires much attention and the elucidation of new facts may be expected to have an important bearing on the work of malarial sanitation.

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APPENDIX I.

Monthly normals for maximum and minimum temperatures, relative humidity, rainfall, and rainy days in Quetta, Baluchistan.*

Month.	Mean maximum temperature (°F.).	Mean minimum temperature (°F.).	Mean relative humidity at 8 hours (per cent).	Total rainfall in inches.	Mean number of rainy days.
January	51·2	28·5	83	1·93	4·7
February	53·2	30·9	81	1·86	4·4
March	63·6	38·8	68	1·88	5·0
April	73·7	45·6	59	1·03	2·9
May	83·8	52·0	51	0·37	1·0
June	91·1	58·5	50	0·15	0·4
July	93·4	64·6	61	0·63	1·3
August	91·6	61·5	63	0·46	0·8
September	85·9	49·5	60	0·07	0·2
October	75·5	38·7	64	0·13	0·3
November	65·4	32·4	77	0·32	0·9
December	56·0	28·7	82	0·92	2·3

* These figures refer to the normals for the meteorological station maintained at the Civil Hospital, Quetta, up to 1928, when a new site was selected at the Royal Air Force lines. We are much indebted to the Director-General of Observatories, Poona, for kindly supplying us with the information given in this Appendix.

APPENDIX II.

Showing the association of anophelines in 167 collections of larvae from the Quetta area, and the number of occasions on which the various combinations were observed.

superpictus *culicifacies* *stephensi*	18 occasions
superpictus *culicifacies* *stephensi* *turkhudi* *dthali*	13 occasions
superpictus *culicifacies*	9 occasions
superpictus *stephensi* *turkhudi* *dthali*	7 occasions
superpictus *culicifacies* *turkhudi*	6 occasions
superpictus *dthali*	5 occasions
superpictus *culicifacies* *dthali*	5 occasions
culicifacies	4 occasions
superpictus *culicifacies* *stephensi* *dthali* *pulcherrimus*	3 occasions
superpictus *culicifacies* *stephensi* *turkhudi*	15 occasions
superpictus *culicifacies* *stephensi* *dthali*	9 occasions
superpictus *stephensi*	8 occasions

superpictus	7 occasions
superpictus *stephensi* *dthali*	5 occasions
stephensi	5 occasions
superpictus *culicifacies* *stephensi* *pulcherrimus*	4 occasions
superpictus *turkhudi*	4 occasions
superpictus *culicifacies* *stephensi* *turkhudi* *dthali* *moghulensis*	3 occasions
superpictus *culicifacies* *moghulensis*	3 occasions
superpictus *culicifacies* *dthali* *turkhudi*	2 occasions
culicifacies *stephensi* *turkhudi*	2 occasions
superpictus *stephensi* *turkhudi* *dthali* *moghulensis*	2 occasions
superpictus *culicifacies* *stephensi* *turkhudi* *dthali* *moghulensis* *pulcherrimus*	1 occasion
superpictus *culicifacies* *stephensi* *dthali* *moghulensis* *fluviatilis*	1 occasion
superpictus *culicifacies* *stephensi* *dthali* *multicolor*	1 occasion
superpictus *culicifacies* *stephensi* *turkhudi* *fluviatilis*	1 occasion
superpictus *culicifacies* *turkhudi* *moghulensis*	1 occasion
dthali *superpictus* *turkhudi*	3 occasions
superpictus *stephensi* *dthali* *moghulensis*	2 occasions
culicifacies *stephensi*	2 occasions
culicifacies *stephensi* *dthali*	2 occasions
culicifacies *superpictus* *stephensi* *turkhudi* *dthali* *moghulensis* *sergenti*	1 occasion
superpictus *culicifacies* *stephensi* *turkhudi* *dthali* *sergenti*	1 occasion
superpictus *culicifacies* *stephensi* *dthali* *moghulensis*	1 occasion
superpictus *culicifacies* *lindesayi* *fluviatilis*	1 occasion
superpictus *culicifacies* *stephensi* *fluviatilis*	1 occasion
superpictus *culicifacies* *stephensi* *turkhudi* *pulcherrimus*	1 occasion

superpictus *culicifacies* *stephensi* *turkhudi* *subpictus*	1 occasion
superpictus *stephensi* *lindesayi*	1 occasion
superpictus *sergenti*	1 occasion
superpictus *stephensi* *sergenti* *dthali*	1 occasion
superpictus *culicifacies* *stephensi* *habibi*	1 occasion
superpictus *culicifacies* *stephensi* *moghulensis*	1 occasion
superpictus *stephensi* *multicolor*	1 occasion
turkhudi	1 occasion

Records of the Malaria Survey of India, 6, 3, September, 1936.

MALARIA IN SIND.

Part XV.

THE EFFECTS PRODUCED BY THE OPERATION OF THE LLOYD BARRAGE SCHEME ON THE INCIDENCE OF MALARIA IN SIND.

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[12th June, 1936.]

INTRODUCTION.

THE Sind Malaria Inquiry commenced its work in the year 1927, when preliminary investigations were undertaken by Lieut.-Colonel T. C. McCombie Young, I.M.S., and Jemadar Abdul Majid, I.M.D., who carried out field surveys in the Upper Sind Frontier, Sukkur and Larkana districts, in northern Sind. Their report included an analysis of the taluka epidemic figures for the whole of the Province, and a discussion as to the probable effects of the Lloyd Barrage Project on the incidence of malaria (Young and Majid, 1930).

From May 1928 until May 1935, Rai Sahib J. D. Baily, I.M.D., was in charge of the field work, under the general direction of Lieut.-Colonel G. Covell, I.M.S. Systematic malaria surveys were undertaken in selected areas in all the talukas of Sind which were to come under the operation of the Barrage Scheme, and also in certain tracts lying outside this area.

With the small staff at our disposal, it has naturally been impossible to carry out surveys at frequent intervals and at the same time in all parts of the Province. To do this adequately, it would have been necessary to have a complete malaria unit constantly at work in every taluka throughout the period. In order to carry out the observations which are briefly summarised in the present paper, it has been necessary for the personnel of the Sind Malaria

Inquiry to be on tour for the greater part of each year. During the course of the investigation, approximately 145,000 spleen examinations and 35,000 blood examinations have been carried out. The work has been rendered the more arduous on account of the difficulties of transport and unfavourable climatic conditions.

From the data thus obtained, it has been possible to form an idea of the various malaria problems of the Province, and of the amount of malaria existing in the different districts both before and after the Barrage Scheme came into operation, in 1932*. A detailed account of the various surveys which have been carried out has been given in a series of papers which have appeared from time to time in the *Records of the Malaria Survey of India.* In the present paper an attempt has been made to assess the effects of the first three years of the operation of the Barrage Scheme on the incidence of malaria in Sind.

In this discussion there are two considerations which must be borne in mind. The first is that, at any rate throughout the period during which reliable records have been maintained, Sind has been visited from time to time by severe regional epidemics of malaria. These, as was pointed out by Young and Majid (*loc. cit.*) from a study of the mortality statistics over a number of years, occur at intervals of approximately 10 years, and chiefly affect northern Sind. One such epidemic occurred in 1929, and was studied in detail by the present authors (Covell and Baily, 1932). The occurrence of these epidemics affect the spleen rate for a considerable period, often as long as five years, after the epidemics themselves have subsided.

A second important consideration is that the amount of rainfall in Sind, which is often scanty and precarious, varies greatly both in amount and distribution from year to year. The Table given below, taken from Hawes (1932), gives the average maximum and minimum amounts of rainfall recorded yearly in the seven districts of Sind over a period of 35 years.

District.	RAINFALL IN INCHES.				
	Average.	MAXIMUM.		MINIMUM.	
		Amount.	Year.	Amount.	Year.
Karachi (at Karachi) ..	7·44	22·05	1916	0·59	1899
Hyderabad (at Hyderabad)	7·03	23·39	1929	0·40	1899
Sukkur (at Sukkur) ..	2·87	11·10	1929	0·03	1898
Larkana (at Larkana) ..	3·28	17·70	1917	0·41	1899
Nawabshah (at Nawabshah)	6·16 *	25·44	1929	0·16	1918
Thar and Parkar (at Mirpurkhas).	8·54	51·34	1929	0·06	1899
Upper Sind Frontier (at Jacobabad).	3·80	10·88	1917	0·67	1927

* 25 years' average only.

Further details as to rainfall in Sind are given in Appendix A.

The surveys which were carried out during the pre-Barrage period showed that the incidence of endemic malaria varied widely in different areas. Thus,

* In this paper, the period before 1932 is alluded to as the 'pre-Barrage period'.

in heavily irrigated rice-growing tracts, malaria was found to be hyperendemic throughout such areas. In other parts of Sind, the amount of endemic malaria varied according as local conditions were favourable or unfavourable for the breeding of malaria-carrying mosquitoes. Thus, villages situated on the banks of 'dead' rivers (*e.g.*, the 'Sind Dhoro', a former bed of the Indus) were invariably highly malarious. Villages where extensive date palm cultivation was carried out were also highly malarious, especially during the first few years of growth of the palms, when they were heavily irrigated. A high incidence of malaria was also common in villages lying between the bed of the Indus and the flood protection embankments, a tract subject to annual flooding from the river. On the other hand, villages in dry crop tracts which were not situated near 'dead' river beds usually showed low spleen rates, unless the area had recently been visited by a regional epidemic of malaria.

It is thus evident that certain areas in Sind were constantly highly malarious long before the Barrage Project was contemplated, that the Province has been subject to regional epidemics of malaria at intervals for at least as long as reliable records have been kept, and that the rainfall in Sind, on which the incidence of malaria largely depends, is both unevenly distributed and varies greatly in amount from year to year.

It is well that these considerations should be borne in mind when assessing the effects of the Barrage Scheme on malaria conditions in Sind, because there is a tendency in some quarters to attribute most, if not all, of the present incidence of malaria in the Province to the operation of the Project.

CONDITIONS FAVOURING AN INCREASE IN MALARIA INCIDENCE RESULTING FROM THE OPERATION OF THE BARRAGE SCHEME.

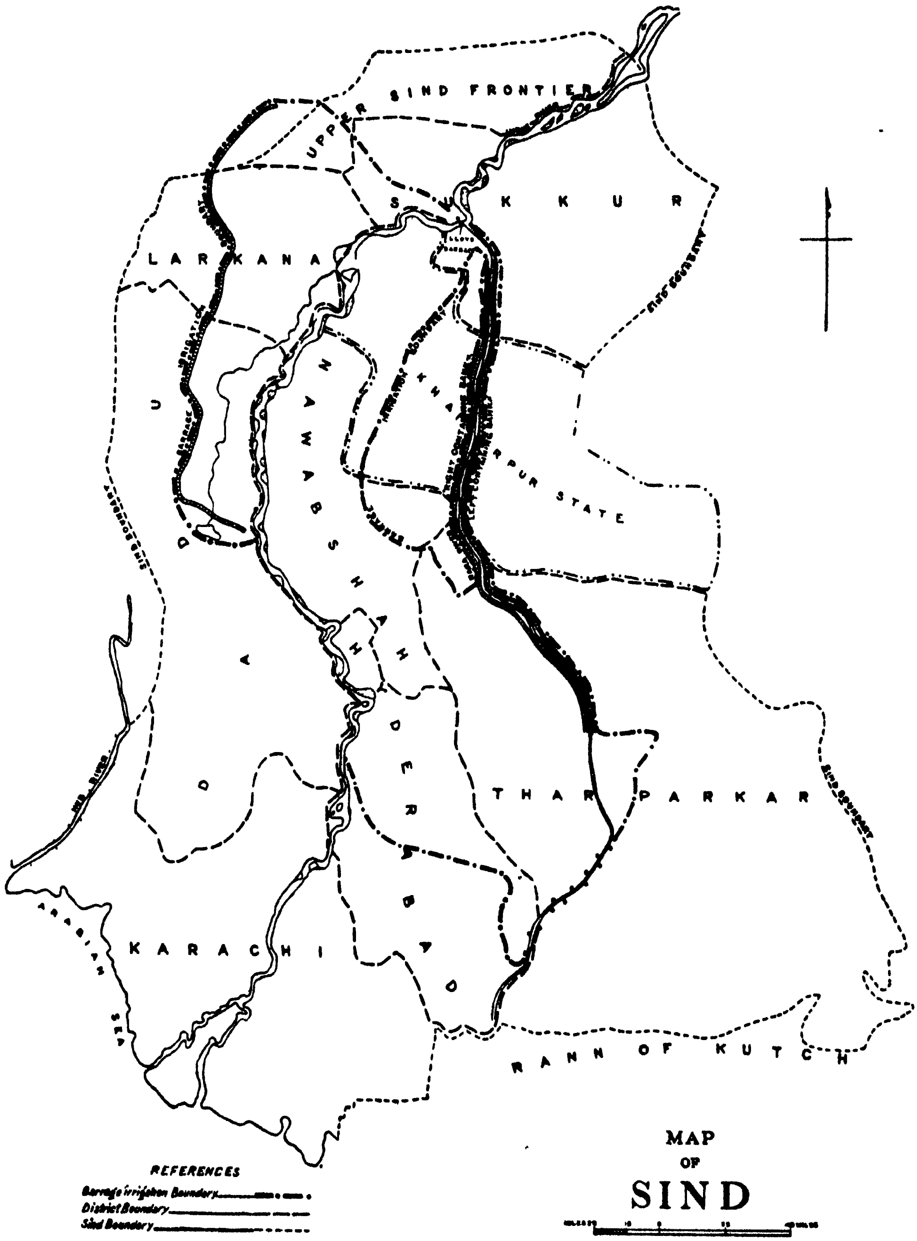
EFFECTS PRODUCED BY THE BARRAGE ITSELF.

The obstruction to the flow of water in the Indus by the operation of the Barrage has resulted in the formation of a pond or lake above it, raising the water level in the river during the winter months for a distance of about 40 miles upstream. The inflow of seepage water from the surrounding country which formerly occurred during these months is thus hindered. Channels supplying the 'dhands' (swamps or ponds) in the neighbourhood of the river, which were formerly dry or almost dry during the winter, now contain water throughout the year. The rise in subsoil water level is especially marked throughout the first 25 miles upstream from the Barrage, notably on the left bank in Rohri, Pano Akil and Ghotki talukas.

A tract of land about 500 acres in extent, opposite New Sukkur, is threatened with water-logging as the result of seepage from the Barrage lake and from the bed of the new head of the Eastern Nara. Certain small inundation canals, which take off from the river immediately north-east of Sukkur, now contain water throughout the winter, and this has raised the subsoil water level in the adjoining tracts. There is also a considerable increase of water throughout the year in the 'Sind Dhoro', with a corresponding rise in the subsoil water level along its course.

Another effect which has been attributed to the Barrage is the erosion of the flood restriction embankment in Rohri taluka. This is said to be due to the waves set up in the lake by the operation of the Barrage gates. Four

Map.


UPPER SIND FRONTIER
SUKKUR
LARKANA
DADU
NAWABSHAH
KHAIRPUR STATE
THAR PARKAR
HYDERABAD
KARACHI
ARABIAN SEA
RANN OF KUTCH
REFERENCES
Barrage Irrigation Boundary
District Boundary
Sind Boundary
MAP
OF
SIND

villages in the immediate vicinity of the embankment have been flooded, and two others are threatened.

The increased supply of water rendered available by the creation of the Barrage lake, together with the re-modelling of certain of the pre-existing canals, has led to a great extension in rice cultivation in several areas in northern Sind, notably in the neighbourhood of Jacobabad. This has led to a serious rise in the subsoil water level in these areas. Although the affected tracts do not come under the command of the Barrage Canals proper, the increase in the amount of water which is being poured on to the land is due indirectly to the operation of the Barrage Scheme.

SEEPAGE FROM NEW CANALS.

An example of this is the serious water-logging which has occurred owing to seepage from the great Rohri Canal during its passage through Khairpur State, an area of about 4,000 acres being involved. A detailed account of the effects on the incidence of malaria produced in this area has been published by Covell and Baily (1934*d*). There is another area of about 17 square miles lying between the Aror Hills and the new Eastern Nara Channel which has also given very definite signs of becoming water-logged.

SECTIONS OF OLD CANALS NOW DISUSED.

In certain places the original inundation canals are still utilised for part of their course, whilst many loops of the old canals have been cut off, forming backwaters. This produces conditions comparable with those in the 'dead' river beds already alluded to, and malaria will tend to increase in villages situated along their course.

THE RICE TRACT ON THE RIGHT BANK OF THE INDUS.

The subsoil water level in this area was very high (3 to 12 feet) before the Barrage Scheme came into operation. The level of the water table was at its highest at the end of the irrigation season, and at its lowest just before it began, in June. The subsoil had time to recover during the remainder of the year, and to get rid of the additions of water made during the irrigation season before the next year's irrigation commenced. Now, however, the period of the irrigation season in the rice tract has been prolonged by several weeks, and in addition great new perennial canals irrigate the surrounding tracts throughout the year, thus affecting adversely the drainage capacity of the soil (Hawes, *loc. cit.*). There has been a serious rise in the water table in large portions of the rice tract, and there is grave danger that it may become completely water-logged unless some efficient scheme of drainage can be devised.

DRY CROP AREAS.

In areas where the great new perennial canals now bring water throughout the year there has in many cases been a substantial rise in the subsoil water level. Examples of this are to be found in Nawabshah district, and in the Jamrao Canal area.

EFFECTS ON CLIMATIC CONDITIONS.

A possible effect of the introduction of so much water on to the land both earlier and later in the year than was formerly the case, is that there may be

a prolongation of the period during which malaria transmission is possible, owing to a rise in the relative humidity of the atmosphere. The meteorological data recorded by us since the Barrage Scheme began to operate, together with the results of collection and dissection of anopheline mosquitoes, suggest that this has actually occurred; but caution is needed in interpreting these results in view of the known normal variations in the climatic conditions of the Province from year to year.

Young and Majid (*loc. cit.*) raised the question as to whether an extensive increase in irrigation might so modify pressure conditions as to permit the entrance of the south-west monsoon air currents, thus leading to increased precipitation. It is a fact that the annual rainfall in Sind was unusually heavy in the first two years of operation of the Barrage, but it appears to us unlikely that this is attributable to the changed conditions of irrigation.

RESULTS OF MALARIA SURVEYS MADE BEFORE AND AFTER THE BARRAGE SCHEME BEGAN TO OPERATE.

The combined figures for the spleen rates recorded in the various districts and talukas of the area affected by the Barrage Scheme recorded during the period 1927 to 1935 are given in Appendix B, Table I. The figures for individual villages are given in Table II of the same Appendix.

UPPER SIND FRONTIER DISTRICT.

This district consists of a long narrow strip of land situated at the extreme north of the province of Sind. It is chiefly devoted to the cultivation of dry crops, but a considerable amount of rice is grown in Jacobabad taluka, and the area under this crop has greatly increased in recent years. For the purposes of studying malarial conditions the district may be divided into the following tracts :—

(*i*) The area between the flood protection embankment and the Indus, subject to yearly floods.
(*ii*) Villages along the course of the 'Sind Dhoro', a former bed of the Indus.
(*iii*) The dry crop tract.
(*iv*) The low-lying rice tract.
(*v*) The hill tract.

During the pre-Barrage period, four surveys were made in this district, two in 1928 and two in 1930, *i.e.*, in the years immediately preceding and following the regional malaria epidemic of 1929. The results of these surveys were discussed in detail in Part VII of this series of papers (Covell and Baily, 1931*b*). The spleen rates recorded in 1928 were generally low, though some villages showed hyperendemic figures due to local conditions permanently favourable to the transmission of malaria, *e.g.*, those in rice-growing areas or in close proximity to the 'Sind Dhoro'. The results recorded in 1930 were of a similar order to those noted generally throughout northern Sind at this period, *i.e.*, spleen rates were everywhere in the neighbourhood of 80 to 90 per cent. The same villages were revisited in October 1934.

The whole district lies outside the tract which has come under the command of the Barrage Canals proper. The villages visited are all situated more than 40 miles distant from the Barrage lake, so that malarial conditions in them

can scarcely have been directly affected by this. But investigations carried out in 1934 showed that there had been very considerable changes which are attributable indirectly to the operation of the Barrage Scheme and to the increased supply of water provided in the Begari and District Canals system. These were :—

(*a*) A marked rise in the subsoil water level in Jacobabad taluka.

(*b*) An increased amount of water in the 'Sind Dhoro' with an accompanying rise in the subsoil water level in the neighbouring villages.

(*c*) A considerable increase in the amount of rice cultivation in Thul, Kandkot and Jacobabad talukas.

The results of the survey of 1934 showed that in certain villages in dry crop areas the spleen rates have returned to approximately their inter-epidemic level. In others, notably those in areas where there has been a large increase in rice cultivation, the spleen rates, although considerably lower than they were immediately after the epidemic, are still in the neighbourhood of 50 per cent. Ghauspur, on the bank of the 'Sind Dhoro', which had a spleen rate of 63 per cent before the epidemic, still shows practically the same figure, whilst in three other villages in the vicinity of the 'Dhoro' where low spleen rates were recorded in 1928 the corresponding figures in 1934 had risen to from 40 to 50 per cent.

SUKKUR DISTRICT.

This district lies immediately south of the Upper Sind Frontier district in northern Sind, and is traversed throughout its length by the Indus. The cultivation is mainly dry crop, but rice is grown in certain areas situated to the west of the river. During the period 1927 to 1930, six visits were made to various parts of the district, and an account of the surveys carried out was given in Part IX of this series of papers (Covell and Baily, 1934*a*). The villages visited all lie to the east of the Indus, with the exception of Sukkur town and certain neighbouring villages in Sukkur taluka. The same villages were again visited in September and October 1934. Observations carried out in Shikarpur and certain villages nearby form the subject of a special study of the regional malaria epidemics of 1929, and are dealt with in separate papers (Covell and Baily, 1932; 1936).

All the villages visited lie in areas which are outside the tract commanded by the Barrage Canals proper, but a number of them are adversely affected by conditions produced by the operation of the Project. On the right bank of the Indus a section of the old Sukkur Canal has been cut off, and forms a prolific anopheline breeding ground, whilst the tails of certain small inundation canals have been obstructed by new channels, resulting in the creation of large swampy areas close to certain villages. In Rohri taluka, on the opposite side of the river, four of the villages lie in a tract which is threatened with water-logging on account of the rise of subsoil water level produced by the Barrage lake and seepage from the new head of the Eastern Nara. Certain villages in Pano Akil taluka lying along the course of the river are also affected by the rise in the subsoil water level. Other villages in Ghotki and Ubauro talukas are indirectly affected, since they now receive sufficient water to enable them to increase their rice cultivation.

The results of the survey of 1934 were of great interest. The last survey preceding this was undertaken in 1930, the year following the regional malaria

epidemic, and spleen rates were everywhere very high, of the order of 80 to 90 per cent. In 1934, five years after the epidemic, one would have expected the spleen rates to have fallen to their inter-epidemic level, *i.e.*, to approximately what they had been in 1927 and 1928, unless some unusual factor had intervened to prevent it.

When we examine the figures relating to individual villages, we find that this has actually occurred in certain cases, *e.g.*, Old Sukkur, Ghotki, Sawai Kalwar, Khalid, Ghulam Mohammed, whilst in other cases the rates have fallen to about half the epidemic level. In the case of villages in the riverain area within 30 miles upstream from the Barrage, the spleen rates are still as high as 60 per cent, and in some cases over 80 per cent. There can be no doubt that the continuance of these high spleen rates is a result of conditions brought about by the operation of the Barrage Scheme.

LARKANA DISTRICT.

This district is situated on the right bank of the Indus, immediately south of Sukkur district, and in it lies the major part of the great rice-growing tract of Sind. An account of observations made in the district at various periods from 1927 to 1932 has been given in Part XI of this series of papers (Covell and Baily, 1934*c*). A further survey of the same villages was carried out in December 1934.

The results recorded show that malaria is hyperendemic throughout the rice tract proper. Larkana town and certain villages such as Nao Dero (which lies outside the rice tract) showed low spleen rates in the inter-epidemic period. During the regional malaria epidemic of 1929 very high spleen rates were everywhere recorded. In 1932 spleen rates were still very high, and this was attributed by us largely to the effects of the operation of the Barrage Scheme —the raising of the subsoil water level, increased period of summer irrigation, cutting off of loops of the old inundation canals, etc. In December 1934, when another series of observations was made, the figures showed only a very slight decrease, with the sole exception of Larkana town, where the rate among school children had fallen from 71 to 46 per cent.

The 1934 observations confirmed the findings which we discussed at length in our former paper, namely, that the continued very high prevalence of malaria in the rice tract was directly attributable to the altered conditions produced by the operation of the Barrage Scheme.

DADU DISTRICT

This district is situated on the right bank of the Indus, immediately south of Larkana district. An account of investigations carried out in various villages in the district during the period 1928 to 1932 has been given in Part X of this series of papers (Covell and Baily, 1934*b*). Further observations were made in the same villages in February and April 1935.

The great rice tract of Sind extends into the northern part of the district. Here, malaria is hyperendemic, and conditions are the same as those described in the account given above of malaria in Larkana district. Observations made in 1932 showed that spleen rates remained high at that period. No later observations have been made in this part of the district.

In the Manchhar Lake area there was very little change in the spleen rate figures between 1932 and 1934 in villages inside the protection embankment,

with the exception of Akatar, where the figure rose from 20 to 54 per cent. In villages situated outside the embankment there was also but little change, except at Jhangar and Bajar, both of which showed a marked fall in the spleen rate.

As regards villages lying at the foot of the hills, there has again been very little change, except at Johi, where the spleen rate rose from 5 per cent in 1932 to 43 per cent in 1935.

NAWABSHAH DISTRICT.

This district is situated on the left bank of the Indus, immediately south of Khairpur State, which separates it from the eastern half of Sukkur district. It is mainly a dry crop area, but a certain amount of rice is grown in some parts of the district. An account of malaria investigations in five of the talukas of the district during the period December 1928 to January 1929 was given in Part IV of this series of papers (Covell and Baily, 1931*a*). Further observations made in Shahdadpur, Sinjhoro and Kandiaro talukas in 1932 were recorded in Part XIII of the series (Covell and Baily, 1935). The district was again visited during the early months of 1935. At this visit it was found that the subsoil water level had risen considerably in certain areas, and that there had been a great increase in the amount of winter cultivation. On the other hand, it was learnt that a certain amount of rice cultivation which had formerly been practised in some of the low-lying areas of the district had now been stopped. It was also said that certain tracts near the Indus, which were formerly subject to flooding almost every year, had not suffered in this way since the Barrage Scheme had commenced to operate.

A comparison of the data obtained in the pre-Barrage period with the figures recorded in 1935 shows very varying results. It is true that in the majority of the villages there was a marked increase in the spleen rates, to at least double and often very much more than double what it had been in the pre-Barrage period. On the other hand there are some villages where the rates are unchanged, and in a few cases, where there has been a cessation of the annual river floodings, the spleen rates are actually lower than they were in 1928. The most outstanding instance of this is the village of Sadhuja, where the rate has fallen from 78 per cent to 25 per cent. The fact, however, that the spleen rates have decreased in some cases, remained stationary in others, and shown so marked an increase in the majority of cases, leads to the conclusion that the increase is due not to natural causes such as climatic conditions precipitating an epidemic, but to some artificial and local cause, *i.e.*, the conditions produced by the operation of the Barrage Scheme. That this is so is made more certain by the fact that the villages which show the greatest increase in the spleen rate are those which have received new distributaries and greatly increased irrigation; in such villages the subsoil water level has often been raised by some 6 to 15 feet.

MIRPURKHAS DIVISION OF THAR AND PARKAR DISTRICT (JAMRAO CANAL AREA).

This is an entirely dry crop area under the command of the Jamrao Canal, which is fed from the Eastern Nara. The latter has been provided with a new head under the Barrage Scheme, and in consequence the cultivation watered by perennial irrigation has enormously increased.

An account of observations made in 1928 in this area was given in Part II of this series of papers (Covell and Baily, 1930). Further observations were made in the same villages in February 1935.

At the second visit the subsoil water level was found to have risen in certain places by some 4 to 8 feet. The villagers and also certain local officials gave it as their opinion that the incidence of malaria since the Barrage Project commenced to operate had definitely increased. This was corroborated by the great increase which was recorded in the spleen rates. The combined figures for the villages visited in Mirpurkhas taluka had risen from 26 to 62 per cent, in Jamesabad taluka from 23 to 70 per cent, and in Digri taluka from 36 to 70 per cent.

DISCUSSION.

In discussing the effects of the operation of the Barrage Project on the incidence of malaria in Sind, the following extracts from the report submitted by Young and Majid on their preliminary field survey of 1927-28 are of interest :—

'In the rice areas in particular, the flooding of the country with pancho water will be greatly reduced, and the provision which has been made for a special system of drainage leading off the surplus water of the rice-growing areas fed by the Central Rice Canal to the Manchhar Lake, *if reasons of economy do not lead to its elimination from the scheme**, should further add to the decrease of the water-logging of the rice-growing areas'.

'*If wise revenue administration can ensure that a reasonable proportion of its profits reaches the cultivator**, and that they do not all go to swell the income of the zamindars and the hoards of the banias, *and if the engineers can prevent the evil of water-logging**, one may not unreasonably regard the Barrage Scheme as the only practical antimalaria measure for Sind, inasmuch as it will improve the economic condition of the people, and will largely eliminate the inundation factor which is associated with epidemic malaria'.

In the introductory section of the present paper we pointed out that many parts of Sind have been highly malarious for at least as far back as reliable records go, and that during this period the Province has been subject to regional epidemics of malaria at intervals. The suggestion that most, if not all, of the malaria now existing in Sind has been produced by the operation of the Barrage Project is thus without foundation.

On the other hand, we have also shown that in many places there has been a marked increase in the incidence of malaria since the Barrage Scheme came into operation†; whilst in the areas which were most affected by the regional epidemic of 1929 there are a number of villages where, although the spleen rates are lower than those recorded immediately after the epidemic, yet they remain very much higher than in the inter-epidemic period. For reasons which we have discussed in detail under the headings of the various districts concerned,

* The italics are ours.

† The following is an extract from a letter dated 19th March, 1935, from the Director of Public Health, Bombay Presidency, to the Director, Malaria Survey of India:—'During my recent tour in Sind I have heard innumerable complaints about the increase of malaria, particularly the recent increase in Thar and Parkar district in the vicinity of Mirpurkhas'.

we are of opinion that these results are due in the main to conditions favouring malaria transmission produced by the operation of the Barrage Scheme*.

It is not to be wondered at that the introduction of such a gigantic irrigation project as the Lloyd Barrage Scheme should result in an increase of malaria incidence, at any rate during the first few years of its operation. Under ideal conditions, where the area to be irrigated has never had canals before, where conditions are favourable for installing an adequate system of drainage for the area, and ample funds are available for carrying out this latter part of the project, which is of such vital importance from both the agricultural and sanitarian points of view, it might be possible to avoid an increase in malaria. But where the scheme has to be carried out in an area where an old and obsolete irrigation system already exists, and where the drainage problem is fraught with difficulty, some increase in malaria is probably unavoidable.

To the malariologist, however, it seems strange that the Research Division of the Irrigation Department, which had for its object the investigation of subsoil conditions in the area to be commanded by the Barrage Scheme, was not constituted until 1930, seven years after work on the Project had been commenced. We would like to subscribe wholeheartedly to the principles laid down in the following extract from the illuminating paper by Hawes to which we have already referred (*loc. cit.*):—'The results obtained so far indicate that it is advisable (it might almost be said, essential), before any large irrigation project is undertaken in future, to make a subsoil and soil survey of the area involved. Many advantages would be obtained from such a survey, since the information obtained would weigh very considerably in making a decision as to whether irrigation should be applied to any area or not. Further, information in regard to the arrangement of the soil strata would be invaluable when the alignment of canals was being worked out. On the right bank of the Indus, in the area commanded by the Barrage Canals, the Rice Canal and the Dadu Canal, which run roughly parallel to each other, are both aligned on one of the sand belts. The losses from these canals are likely, therefore, for the first few years, to be very considerable indeed; these losses might perhaps have been considerably reduced by aligning the channels to take advantage, as far as possible, of the clay belts, in which seepage losses would be very considerably less than in the sand belts'.

The next question which arises is whether the adverse effect of malarial incidence which we have attributed to the working of the Barrage Scheme is likely to continue. It is difficult to answer this question definitely at the present stage, but it seems to us likely that there will be some permanent increase in endemic malaria in the areas where there has been a great extension of perennial irrigation. In tracts which are threatened with water-logging, the future as regards malarial incidence depends on the degree of success obtained by the Irrigation Department in providing efficient drainage. If their efforts fail, and large areas are rendered unfit for cultivation on account of water-logging, the

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*The Central Board of Irrigation does not, however, share this view, *vide* their resolution passed in November 1935, which reads :—'The Central Board of Irrigation have noted that the Conference of Medical Research Workers find that there has been an increase in the incidence of malaria in Sind, but do not consider there is sufficient evidence to decide the cause. The Board agree with the Conference of Medical Research Workers that close co-operation between the Irrigation and Medical authorities to prevent the increase of disease is desirable'.

outlook is grave indeed; for not only will the incidence of malaria be increased, but the people will be faced with the prospect of economic stress as the result of the failure of their crops.

If, however, the drainage difficulties are so far overcome as to add materially to the economic prosperity of the villagers, the latter will no doubt eventually adapt themselves to the altered conditions. It is highly probable that if the average villager were asked whether he would rather receive a material increase in his income plus a greater liability to fever or remain in his present circumstances, he would unhesitatingly choose the former alternative.

Apart from the complex engineering problems which are engaging the attention of the Irrigation Department, and in which the interests of agriculture and public health go hand in hand, we would most strongly urge that every effort be made to increase facilities for the treatment of malaria throughout the area commanded by the Barrage Scheme. It would seem just that the cost of such measures should be allocated as a part of the obligations to be met from the budget of the Barrage Project.

We would also urge that wherever possible the rest-houses used by officials touring in Sind should be screened with mosquito-proof wire gauze and equipped with electric light and fans. This should not be regarded as an unnecessary extravagance, but as a wise measure of public health insurance. We have no hesitation in stating that the expense thereby incurred will be amply repaid by the decrease in sickness among the officials concerned.

SUMMARY.

(1) Before the Lloyd Barrage Scheme commenced operations, many parts of Sind were highly malarious, and the Province was subject to periodical epidemics of malaria, more especially affecting the northern areas. The contention put forward in certain quarters that most, if not all, of the malaria now existing in Sind is due to the operation of the Barrage Scheme, is thus unsupported by facts.

(2) Nevertheless it is a fact that malarial conditions in Sind have become considerably worse since the Barrage Scheme began to operate, and we consider that this is due mainly to conditions favouring the spread of malaria brought about by the operation of the Scheme.

(3) The principal factors which have produced this adverse effect are :—

(*i*) A rise in the subsoil water level in many areas.

(*ii*) Actual or threatened water-logging of the soil in certain areas.

(*iii*) Seepage from some of the new canals.

(*iv*) The cutting off of sections of certain of the old canals, thus forming prolific anopheline breeding grounds.

(*v*) The formation of a 'lake' above the Barrage, with a corresponding rise of the subsoil water level along the course of the Indus.

(*vi*) An extension in rice cultivation in areas outside the Barrage Command in northern Sind, due to the increased supply of water made available by the presence of the Barrage lake and the re-modelling of pre-existing canals.

(4) The future course of event as regards the incidence of malaria depends on the degree of success attained by the Irrigation Department in providing efficient drainage, and preventing the evils of water-logging.

(5) It is strongly urged that increased facilities for the treatment of malaria be provided throughout the area affected by the Barrage Scheme.

(6) We also recommend that where possible all rest-houses provided for officials touring in Sind be rendered mosquito-proof and equipped with electric light and fans.

(7) Attention is drawn to the vital importance of making a soil and subsoil survey of the area involved, as well as providing an efficient scheme of drainage, before any large irrigation project is undertaken.

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APPENDIX A.

Rainfall figures in inches during the period July to September recorded at various stations in Sind for the years **1928** *to* **1934.**

Locality.	1928	1929	1930	1931	1932	1933	1934
SUKKUR DISTRICT.							
Sukkur ..	1·10	10·69	0·84	0·20	3·09	5·89	1·10
Garhi Yasin ..	0·02	9·08	2·22	0·22	2·08	6·19	1·16
Shikarpur ..	0·34	11·97	2·93	0·64	2·44	3·32	0·00
Pano Akil ..	0·13	10·02	2·56	0·13	6·70	9·85	0·69
Ghotki ..	0·12	6·97	0·91	0·31	4·03	8·66	0·68
Ubauro ..	1·00	6·10	4·47	2·84	6·49	8·34	0·00
Mirpur Mathelo	0·24	7·46	1·79	0·88	7·42	12·65	0·47
Rohri ..	0·55	11·36	0·79	0·11	2·20	6·35	0·56
UPPER SIND FRONTIER DISTRICT.							
Jacobabad ..	0·40	5·43	2·36	0·01	4·86	5·10	3·11
Thul ..	2·95	9·51	1·21	0·75	2·46	5·87	2·76
Kandhkot ..	0·26	17·65	0·71	1·69	1·74	4·53	0·28
Kashmor ..	0·42	21·95	1·24	0·66	2·33	5·02	0·34
LARKANA DISTRICT.							
Larkana ..	0·00	11·32	1·15	0·07	3·01	10·60	1·60
Labdarya ..	0·00	9·50	0·85	0·20	6·94	6·02	0·21
Warah ..	0·06	6·76	2·06	1·70	4·66	7·69	0·00
Kambar ..	0·00	8·03	1·68	0·11	4·51	7·43	0·91
Ratodero ..	0·00	7·10	1·32	0·07	3·65	5·42	1·11
Shahdadkot ..	0·23	6·99	1·84	0·52	6·73	6·84	1·46
DADU DISTRICT.							
Kotri ..	0·45	19·51	1·05	1·51	3·59	5·68	5·08
Kohistan ..	..	..	..	..	7·00	10·56	4·05
Sehwan ..	0·09	15·53	3·84	1·68	6·41	2·21	0·55
Dadu ..	0·00	9·83	2·08	0·73	5·40	2·77	0·00
Johi ..	1·10	7·92	2·85	0·58	2·43	3·59	0·53
Kakar ..	0·55	9·24	1·53	1·10	5·92	5·57	0·00
Mehar ..	0·06	10·85	0·71	2·58	5·68	5·88	0·06
NAWABSHAH DISTRICT.							
Nawabshah ..	0·36	24·75	2·61	3·93	4·35	3·71	2·17
Sinjhoro ..	3·47	32·72	1·58	1·73	5·11	4·54	2·89
Shahdadpur ..	0·97	27·86	4·41	1·91	5·10	3·62	3·35
Tando Adam ..	1·66	36·73	4·79	3·07	3·29	8·69	3·14
Sakrand ..	0·04	25·12	7·54	2·82	6·90	5·90	3·30
Moro ..	0·08	15·65	2·10	1·28	15·63	4·45	0·79
Naushahro ..	0·33	13·57	0·88	0·43	13·76	5·79	0·05
Tharushah ..	0·70	16·10	0·00	0·62	7·02	4·61	0·41
Kandiaro ..	1·22	10·34	2·53	0·84	4·30	1·39	0·28

APPENDIX A—*concld.*

Locality.	1928	1929	1930	1931	1932	1933	1934
THAR AND PARKAR DISTRICT.							
Mirpurkhas ..	2·25	47·44	2·98	6·33	6·03	7·74	1·06
Pithoro ..	1·68	21·28	1·90	5·52	4·59	3·80	3·69
Jamesabad ..	3·77	31·19	1·19	4·51	5·57	4·85	4·05
Digri ..	3·10	25·84	2·99	2·68	5·99	4·47	2·54
Diplo .	5·74	25·48	6·81	3·78	12·76	14·41	3·50
Mitti .	5·33	16·74	2·15	5·97	6·64	10·46	3·30
Nagar Parkar ..	5·17	10·96	8·34	10·98	5·50	18·74	13·11
Chachhro ..	4·86	21·59	2·94	12·20	9·28	9·09	5·59
Umarkot ..	3·93	23·52	4·27	5·70	6·86	10·76	7·41
Kipro ..	4·35	32·12	2·90	5·00	5·40	3·69	2·64
Sanghar ..	2·33	28·54	1·11	1·26	3·65	4·44	3·11
HYDERABAD DISTRICT.							
Hyderabad ..	1·24	21·40	1·11	0·93	3·60	7·79	6·43
Hala ..	0·15	27·76	6·29	1·63	3·62	4·62	2·60
Tando Allahyar ..	2·86	33·81	2·25	3·58	6·97	2·59	0·78
Dero Mahbat .	1·85	23·48	4·99	3·47	5·00	8·66	3·25
Tando Bago ..	1·29	26·44	3·30	6·10	10·33	9·93	6·84
Badin ..	1·42	20·02	4·62	2·86	7·86	11·97	4·57
Guni ..	1·72	24·71	3·47	1·88	5·21	10·30	3·22
KARACHI DISTRICT.							
Karachi ..	0·68	4·93	12·49	0·18	11·33	21·61	5·99
Manora ..	0·84	2·30	13·43	0·24	12·57	19·74	6·72
Mirpur Sakro .	0·80	7·94	7·11	1·02	13·42	12·61	4·35
Ghorabari ..	1·10	8·87	6·21	0·77	8·72	14·03	4·72
Kati Bunder ..	0·39	2·63	11·58	0·18	11·20	9·53	2·71
Jati ..	3·18	10·57	4·64	1·73	11·90	17·08	4·50
Sahbundar ..	0·53	9·50	6·50	0·61	8·67	13·99	3·05
Sujawal ..	0·79	14·00	4·74	0·81	7·91	10·27	1·11
Mirpur Bathoro ..	2·14	19·01	3·97	1·13	9·06	13·21	1·29
Tatta ..	2·11	10·68	7·45	0·31	10·74	12·65	5·20
Jerruck ..	1·62	18·86	4·77	0·78	5·51	8·03	4·26

APPENDIX B.

TABLE I.

Combined results of spleen examinations of children in various talukas in Sind before and after the Lloyd Barrage Scheme commenced to operate.

Taluka.	PRE-BARRAGE PERIOD.			POST-BARRAGE PERIOD.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
SUKKUR DISTRICT.						
Sukkur	iv.27 x.30	966 1,088	12 85	x.34	1,301	59
Rohri	iv.27 x.30	186 534	8 74	x.34	996	47

APPENDIX B—*concld.*

Taluka.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
SUKKER DISTRICT—*concld.*						
Pano Akil ..	x. 28	518	22	ix. 34	619	53
	x. 30	285	75			
Ghotki ..	ix. 29	544	7	ix. 34	528	29
	iii. 30	401	36			
Mirpur Mathelo	x. 29	135	18	ix. 34	110	63
	iii. 30	85	61			
Ubauro ..	ix. 29	390	9	x. 34	400	40
UPPER SIND FRONTIER DISTRICT.						
Kashmor ..	i. 28	97	11	xi. 34	329	22
	x. 30	198	81			
Kandhkot ..	xi. 28	562	28	x. 34	491	48
	ix. 30	479	88			
Thul ..	i. 28	93	27	xi. 34	578	51
	ix. 30	535	88			
Jacobabad ..	i. 28	125	20	x. 34	738	21
	x. 30	685	71			
LARKANA DISTRICT.						
Ratodero ..	..	..	..	xi. 32	1,139	62
				xii. 34	856	57
Mirokhan ..	..	..	..	xi. 32	498	64
				xii. 34	515	64
Kambar ..	iv. 27	126	45	xi. 32	741	55
	i. 28	83	77	xii. 34	768	51
	vii. 28	150	43			
	xi. 29	229	83			
Warah ..	..	..	..	xi. 32	1,049	58
				xii. 34	1,191	48
Labdarya ..	iv. 27	56	48	xi. 32	870	69
				xii. 34	898	59
Larkana ..	iv. 27	859	35	xi. 32	2,514	74
				viii. 34	2,384	71
				xii. 34	2,822	51
Shahdadkot ..	x. 30	800	81	ii. 35	784	39
DADU DISTRICT.						
Johi ..	iii. 32	769	12	ii. & iv. 35	596	16
Sehwan ..	iii. 32	1,116	25	ii. 35	1,244	26
NAWABSHAH DISTRICT.						
Naushahro ..	xii. 28	320	22	iii. 35	309	40
Moro ..	xii. 28	646	27	iii. 35	534	36
Sakrand ..	xii. 28	726	35	i. 35	713	68
Nawabshah ..	i. 29	315	9	i. 35	468	54
Shahdadpur ..	i. 29	232	18	i. 35	236	56
MIRPURKHAS DIVISION (THAR AND PARKAR DISTRICT).						
Digri ..	viii. 28	276	36	ii. 35	243	74
Jamesabad ..	viii. 28	234	23	ii. 35	231	70
Mirpurkhas ..	viii. 28	394	26	ii. 35	580	62

TABLE II.

Results of spleen examinations of children in various villages in Sind before and after the Lloyd Barrage Scheme commenced to operate.

Locality.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
SUKKUR DISTRICT.						
Sukkur Taluka.						
Punjabi ..	iv.27 x.30	25 29	20 93	x.34	65	60
Rahuja ..	iv.27 x.30	22 41	5 88	x.34	50	64
Abad Lakha ..	iv.27 x.30	40 104	0 86	x.34	100	49
Arain ..	iv.27 x.30	62 63	8 86	x.34	120	62
Shahpur ..	iv.27 x.30	15 24	0 96	x.34	50	76
Lakhi ..	iv.27 x.30	103 150	4 93	x.34	125	81
Dodogot ..	iv.27 x.30	25 24	8 88	x.34	25	76
Jahan Khan ..	iv.27 x.30	31 52	18 90	x.34	60	82
Kassim ..	iv.27 x.30	106 60	5 83	x.34	70	79
Bichanji ..	iv.27 x.30	128 60	28 87	x.34	90	77
Gosarji ..	iv.27 x.30	25 90	0 79	x.34	115	72
Old Sukkur ..	iv.27 x.30	207 270	23 80	x.34	281	33
New Sukkur ..	..	..	..	x.34	415	6
Bagarji ..	iv.27 x.30	87 121	6 76	x.34	150	45
Rohri Taluka.						
Kandra ..	iv.27 x.30	160 112	3 59	x.34	205	70
Miani Bhagat ..	iv 27 x.30	26 48	39 92	x.34	60	78
Thatli and Tando Mohd. Khan.	x.30	63	81	x.34	105	82
Borah ..	x.30	35	89	x.34	40	73
Begmaji ..	x.30	54	74	x.34	11	91
Patni ..	x.30	62	89	x.34	175	50
Rohri ..	x.30	160	68	x.34	400	16
Pano Akil Taluka.						
Pano Akil ..	x.28 x.30	120 70	13 67	ix.34	205	30
Url and Jani Jo ..	x.28 x.30	61 41	28 90	ix.34	48	44

TABLE II—*contd.*

Locality.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
			PANO AKIL TALUKA—*concld.*			
Shahpur ..	x.28 x.30	44 10	27 70	ix.34	27	63
Sawai Kalwar ..	x 28 x 30	52 28	25 68	ix.34	45	33
Nidhapur ..	x.28 x 30	110 40	28 63	ix.34	100	60
Pitafi ..	x 28 x.30	20 21	10 57	ix.34	39	56
Fateh Khan Jo Got.	x.28	20	15	ix.34	..	..
Satarna ..	x.28	21	29	ix.34	26	100
Khan Bela ..	x.28	10	20	ix.34	32	81
Samo Chachar ..	x.28	24	8	ix.34	42	81
			GHOTKI TALUKA.			
Ghotki ..	ix 29 iii 30	239 200	5 26	ix.34	250	9
Qaderpur ..	ix 29 iii 30	145 134	7 46	ix.34	166	31
Hussain Beli ..	ix.29 iii.30	75 47	12 47	ix.34	47	72
Mathelo ..	ix.29 iii.30	85 20	11 50	ix.34	65	74
			MIRPUR MATHELO TALUKA.			
Mirpur Mathelo	ix.29 iii.30	135 85	18 61	ix.34	110	64
			UBAURO TALUKA.			
Ubauro ..	ix.29	144	10	x.34	142	50
Jhangal Mohana	ix.29	12	17	x.34	11	45
Matar Kot ..	ix.29	32	16	x.34	43	40
Dharki ..	ix.29	149	14	x.34	151	28
Langha ..	ix.29	53	28	x.34	53	47
			UPPER SIND FRONTIER DISTRICT.			
			KASHMOR TALUKA.			
Kashmor ..	i.28	62	11	xi.34	200	25
Ghulam Mohd. ..	x.30 i.28 x.30	111 35 30	82 11 73	xi.34	43	14
Dakhan ..	x.30	30	83	xi 34	43	37
Qader Baksh ..	x.30	7	100	xi.34	8	13
Dasti and Atta Mohd.	x.30	20	75	xi.34	35	3

TABLE II—*contd.*

Locality.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
		KANDHKOT TALUKA.				
Kandhkot ..	i. 28 ix. 30	92 201	28 84	x. 34	235	40
Haybat ..	i. 28 ix. 30	39 58	27 88	x. 34	48	50
Dari ..	xi. 28 ix. 30	110 100	21 92	x. 34	78	47
Ghauspur ..	xi. 28 ix. 30	178 120	63 92	x. 34	130	62
		THUL TALUKA.				
Chana ..	ix. 30	121	93	xi. 34	125	50
Mirpur ..	ix. 30	123	86	xi. 34	180	56
Mir Hasan ..	i. 28 ix. 30	27 53	33 83	xi. 34	39	46
Garhi Hasan ..	ix. 30	57	86	xi. 34	54	33
Thul ..	i. 28 ix. 30	66 181	24 87	xi. 34	180	53
		JACOBABAD TALUKA.				
Jacobabad ..	i. 28 ix. 30	100 347	17 65	x. 34	420	21
Jatohi ..	i. 28 ix. 30	25 35	32 89	x. 34	43	9
Sadik Bangar ..	ix. 30	17	77	x. 34	19	26
Dil Murad Khoso	ix. 30	77	82	x. 34	60	30
Bhalaidina Abad	ix. 30	92	79	x. 34	109	27
Ramzanpur ..	ix. 30	37	62	x. 34	27	7
Maulabad ..	ix. 30	60	70	x. 34	60	23
		LARKANA DISTRICT.				
		RATODERO TALUKA.				
Naodero ..	xi. 32	145	65	xii. 34	140	51
Ratodero ..	xi. 32	295	57	xii. 34	190	64
Pir Jo Got ..	xi. 32	100	68	xii. 34	73	52
Panjo Dero ..	xi. 32	88	82	xii. 34	120	72
Khan Wah ..	xi. 32	73	63	xii. 34	50	50
Pir Baksh Bhuto	xi. 32	67	66	xii. 34	80	51
Masu Dero ..	xi. 32	40	67	xii. 34	62	55
Ghari Khuda Baksh.	xi. 32	55	53	xii. 34	19	63
Bungal Dhero ..	xi. 32	276	59	xii. 34	122	45
		MIRO KHAN TALUKA.				
Chowsool ..	xi. 32	47	79	xii. 34	42	60
Miro Khan ..	xi. 32	80	50	xii. 34	110	66
Joya ..	xi. 32	65	61	xii. 34	60	72
Langhari ..	xi. 32	18	44	xii. 34	26	65
Tharo Wadho ..	xi. 32	40	77	xii. 34	38	74
Sujawal ..	xi. 32	102	60	xii. 34	90	50
Banglow Mahbab	xi. 32	58	69	xii. 34	55	67
Buthi ..	xi. 32	58	72	xii. 34	60	77
Bahram Hethian	xi. 32	30	60	xii. 34	34	50

TABLE II—*contd.*

Locality.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
Kambar Taluka.						
Kambar ..	xi. 32	200	48	xii. 34	210	42
Bher ..	xi. 32	110	57	xii. 34	120	40
Ghatahar ..	xi. 32	115	59	xii. 34	102	51
Hani ..	xi. 32	47	66	xii. 34	60	53
Mena ..	xi. 32	83	58	xii. 34	100	66
Hulia ..	xi. 32	45	24	xii. 34	50	52
Got Nur Mohd. Khan.	xi. 32	40	60	xii. 34	26	77
Mehanji Khai ..	xi. 32	67	72	xii. 34	69	71
Daphar ..	xi. 32	34	59	xii. 34	31	45
Warah Taluka.						
Warah ..	xi. 32	185	79	xii. 34	200	72
Nasirabad ..	xi. 32	222	60	xii. 34	221	53
Panhwar and Muradi.	xi. 32	30	50	xii. 34	60	58
Lakha ..	xi. 32	72	60	xii. 34	81	53
Gazi Kuhawar ..	xi. 32	252	40	xii. 34	266	32
Jani Jo Bond ..	xi. 32	108	58	xii. 34	110	46
Haitam Saho ..	xi. 32	55	29	xii. 34	60	45
Wagan ..	xi. 32	125	74	xii. 34	193	38
Labdarya Taluka.						
Dokri ..	xi. 32	151	86	xii. 34	200	77
Badeh ..	xi. 32	300	54	xii. 34	253	42
Darra ..	xi. 32	36	72	xii. 34	45	69
Gerelo ..	xi. 32	220	68	xii. 34	235	55
Tharecha ..	xi. 32	58	84	xii. 34	60	73
Mad Bahu ..	xi. 32	105	83	xii. 34	105	54
Larkana Taluka.						
Larkana ..	xi. 32	1,613	71	xii. 34	1,993	46
Mahota ..	iv. 27	..	54	xii. 34	120	63
	xi. 32	122	85			
Baroch ..	iv. 27	11	36	xii. 34	20	40
	xi. 32	8	87			
Chunna ..	iv. 27	26	46	xii. 34	30	83
	xi. 32	16	94			
Masu Habb ..	iv. 27	..	27	xii. 34	75	71
	xi. 32	120	91			
Khalid ..	iv. 27	25	44	xii. 34	34	27
	xii. 32	61	78			
Akil ..	iv. 27	59	27	xii. 34	37	46
	xii. 32	42	55			
Dhamrah ..	iv. 27	..	17	xii. 34	83	54
	xi. 32	158	67			
Fatehpur ..	iv. 27	..	48	xii. 34	34	74
	xi. 32	66	79			
Dodai ..	..	..	..	xii. 34	82	83
Satardino ..	iv. 27	..	69	xii. 34	21	86
	xi. 32	40	90			

TABLE II—*contd.*

Locality.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
			LARKANA TALUKA—*concld.*			
Kanga ..	iv.27	..	32	xii.34	93	59
	xi.32	112	87			
Nazar ..	iv.27	..	46	xii.34	58	81
	xi.32	53	96			
Berochandia ..	iv.27	..	38	xii.34	84	69
	xi.32	103	84			
Walid ..	xi.32	203	85	xii.34	140	79
			SHAHDADKOT TALUKA.			
Sando ..	x.30	30	93	ii.35	47	53
Changal ..	x.30	25	80	ii.35	10	50
Kot Ali Nawaz	x.30	22	74	ii.35	27	29
Aitbar Khan Chandia.	x.30	30	90	ii.35	48	28
Got Daryakhan	x.30	20	70	ii.35	38	18
Sobdar Mastoi ..	x.30	20	75	ii.35	36	50
Chakiani ..	x.30	40	88	ii.35	44	71
Silra ..	x.30	35	80	ii.35	49	25
Shahdadkot ..	x.30	365	81	ii.35	475	38
			DADU DISTRICT.			
			DADU TALUKA.			
Dadu ..	vii.29	130	22	iv.35	174	18
Makhdoom Bilawal.	vii.29	96	70	iv.35	67	22
Jatohi ..	vii.29	40	22	..	..	..
			JOHI TALUKA.			
Pir Gazi Shah ..	iii.32	31	23	ii.35	23	9
Tando Rahim Khan.	iii.32	90	12	ii.35	65	20
Chhini ..	iii.32	81	7	ii.35	118	2
Shah Hussain ..	iii.32	94	1	ii.35	125	10
Baz Mar Khoso	x.32	47	4	iv.35	27	0
Haji Khan ..	x.32	91	9	iv.35	50	6
Bhawalpur ..	x.32	111	31	iv.35	59	32
Walwani Jamali	x.32	32	41	iv.35	25	4
Johi ..	x.32	192	5	iv.35	104	43
			SEHWAN TALUKA.			
Sehwan ..	viii.28	140	14	ii.34	214	23
				iv.35	164	12
Talti ..	iii.32	75	55	ii.35	124	38
Arija ..	iii.32	116	28	ii.35	84	31
Bhan ..	iii.32	127	54	ii.35	150	49
Akatar ..	iii.32	40	20	ii.35	50	54
Jhangar ..	iii.32	87	40	ii.35	117	7

TABLE II—*contd.*

Locality.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
			SEHWAN TALUKA—*concld.*			
Bajar ..	iii.32	63	30	ii.35	80	10
Bubak ..	iii.32	100	45	ii.35	250	41
Kot Barocho ..	iii.32	32	16	ii.35	28	25
Tehni ..	iii.32	27	11	ii.35	37	11
Naing ..	iii.32	16	25	ii.35	30	43
Miani Garkaro ..	iii.32	124	11	ii.35	110	2
Miani Arisarai ..	iii.32	95	7	ii.35	20	15
			MIRPURKHAS DIVISION (THAR AND PARKAR DISTRICT).			
			DIGRI TALUKA.			
Digri ..	viii.28	122	33	ii.35	112	69
Deh 170 ..	viii.28	154	38	ii.35	131	78
			JAMESABAD TALUKA.			
Jamesabad ..	viii.28	120	20	ii.35	125	74
Deh 333 ..	viii.28	114	25	ii.35	106	66
			MIRPURKHAS TALUKA.			
Mirpurkhas ..	viii.28	181	9	ii.35	360	53
Garibabad ..	viii.28	75	44	ii.35	100	74
Mir Yar Mohd.	viii.28	50	14	ii.35	65	83
Jheluri ..	viii.28	88	54	ii.35	64	80
			NAWABSHAH DISTRICT.			
			NAUSHAHRO TALUKA.			
Bhiria ..	xii.28	110	44	iii.35	173	48
Mithani and Abji	xii.28	210	11	iii.35	136	29
			MORO TALUKA.			
Sadhuja ..	xii.28	85	78	iii.35	100	25
Dehran ..	xii.28	45	49	iii.35	33	39
Isaq Chand ..	xii.28	12	25	iii.35	4	25
Moro ..	xii.28	128	18	iii.35	150	28
Daras .	xii.28	125	14	iii.35	95	35
Shahpur ..	xii.28	75	20	iii.35	61	44
Daulatpur ..	xii.28	176	15	iii.35	91	55
			SAKRAND TALUKA.			
Jhunjan ..	i.29	41	19	i.35	70	46
Kazi Ahmed ..	xii.28	57	72	i.35	89	80
Mir Jath and Mohd.	..	16	12	i.35	19	53
Shahni Jo Got ..	xii.28	17	18	i.35	25	60
Rahun ..	xii.28	44	14	i.35	30	80
Dehra, Kaki Chundia and Shakal Chundia.	xii.28	87	22	i.35	69	62
Sukhio Manahi	xii.28	34	12	i.35	26	54

TABLE II—*concld.*

Locality.	Pre-barrage period.			Post-barrage period.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
			SAKRAND TALUKA—*concld.*			
Miani ..	xii.28	63	71	i.35	38	58
Sakrand ..	xii.28	16	44	i.35	56	70
Kumblima ..	xii.28	140	14	i.35	107	83
Mehrabpur ..	xii.28	136	42	i.35	102	62
Mari ..	xii.28	42	69	i.35	54	93
Dala Dehra ..	xii.28	33	24	i.35	28	50
			NAWABSHAH TALUKA.			
Nawabshah ..	xii.28	232	13	i 35	330	59
Fakirji Khuhi ..	xii.28	15	7	i 35	30	60
Rai Bahadur Kawda Mal.	xii.28	36	0	i.35	44	41
Haji Peria, Bida Khan, Jamali and Imam Ali Shah.	xii.28	32	0	i.35	64	38
			SHAHDADPUR TALUKA.			
Sarhari ..	i.29	28	50	i.35	72	46
Nawazdhari ..	i.29	21	47	i.35	11	55
Faiz Mohd. Jo Got.	i.29	19	0	i.35	3	..
Mohd. Kamal Kiria.	i.29	19	10	i.35	25	24
Rangho Khan Talpur.	i.29	68	10	i.35	63	78
Allah Ditta Khas Keli.	i.29	21	14	i.35	23	52
Karam Dad Ketchi.	i.29	31	3	i.35	21	81
Khoto Zardari, Khoto Zakro and Manak Zardari.	i.29	25	16	i.35	18	50

Records of the Malaria Survey of India, 6, 3, September, 1936.

FURTHER OBSERVATIONS ON A REGIONAL EPIDEMIC OF MALARIA IN NORTHERN SIND.

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INTRODUCTION.

REGIONAL epidemics of malaria, characterised by their fulminant nature and their effect on mortality, occur in Sind at intervals of approximately 10 years. The effects of these epidemics are chiefly felt in the northern parts of the Province, where in inter-epidemic periods the incidence of malaria is normally low. One such epidemic occurred in the autumn of 1929. The results of observations made in Shikarpur immediately before the epidemic, during the epidemic period, and during the first eight months of the post-epidemic period were discussed in detail by us in a previous paper (Covell and Baily, 1932). Data recorded in certain villages in the vicinity of Shikarpur during this period were also summarised.

Further investigations in Shikarpur and in the neighbouring villages in Shikarpur and Garhi Yasin talukas have been carried out during the five-year period immediately following the epidemic, and these form the subject of the present paper.

Judging from observations made in various localities in the Punjab, it was expected that the spleen rates recorded in the epidemic area would decrease year by year, and that the figures would have declined to approximately their inter-epidemic level five years after the occurrence of the epidemic. Various influences have however combined to interfere with the natural decline of the spleen rate in northern Sind. The chief of these are :—

(*i*) Unusually heavy rainfall in 1932 and 1933 (*vide* Appendix A).

(*ii*) Extensive floods in 1930 and 1932, as the result of breaches in the flood protection embankments running parallel with the Indus.

(*iii*) An extension of rice cultivation rendered possible by the increased amount of water supplied by the canals irrigating this part of the country. This has resulted in a marked rise in the subsoil water level, with the threat of actual water-logging in certain areas.

(*iv*) The rise in subsoil water level along the course of the Indus, caused by the formation of a 'lake' which has raised the water level in the river during the winter months for a distance of about 40 miles upstream from the Barrage.

The data recorded prior to the epidemic of 1929 showed that in general the incidence of malaria throughout the extreme northern section of the Province was very low. Spleen rates in most of the villages visited were in many cases lower than 10 per cent, and the only locality which showed a high rate was Ghauspur, a village situated on the bank of the 'Sind Dhoro', a former bed of the Indus.

Observations made about eight months after the epidemic showed that the spleen rates were everywhere very high, of the order of 80 to 90 per cent. The data recorded in 1934 and the early months of 1935 showed that whilst in a few instances the spleen rates had declined to their inter-epidemic level, in many other places this was far from being the case. In a number of instances the spleen rates, whilst showing a decline from the high figures of 1930, were still in the neighbourhood of about 50 per cent, whilst in Rohri taluka eight out of nine villages actually yielded spleen rates of between 70 and 80 per cent.

The results of spleen examinations of children made in various localities in northern Sind prior to the regional epidemic, immediately after the epidemic, and five years after the epidemic respectively, are given in Appendix B.

As has been explained in another paper (Covell and Baily, 1936), the adverse effects on malaria conditions in this part of Sind are largely attributable, directly or indirectly, to changes produced by the operation of the Lloyd Barrage Scheme.

RESULTS OF OBSERVATIONS MADE IN SHIKARPUR CITY AND THE NEIGHBOURING VILLAGES.

In our former paper dealing with the regional malaria epidemic of 1929 (Covell and Baily, 1932), we gave in detail the results of spleen and blood examinations made among the school children of Shikarpur City from August 1929 to August 1930. We showed that *P. falciparum* was the principal malaria parasite concerned in the epidemic, and that this species was responsible for most of the mortality. A marked feature of the blood results was an abrupt rise in the crescent rate occurring about the ninth week of the epidemic period, two or three weeks after the morbidity curve reached its highest peak. The few observations made immediately before the commencement of the epidemic indicated that, at that period, crescents were extremely rare.

There were a number of cases of benign tertian malaria in the early stages of the epidemic, but the B. T. parasite rate had fallen almost to zero by the end of the epidemic period. On the other hand, observations made in August 1930 showed a marked increase in the B. T. rate (to 19 per cent), whilst the M. T. rate at this period was very low (5 per cent). As regards spleen examinations, the most remarkable feature was the marked increase in the spleen rate

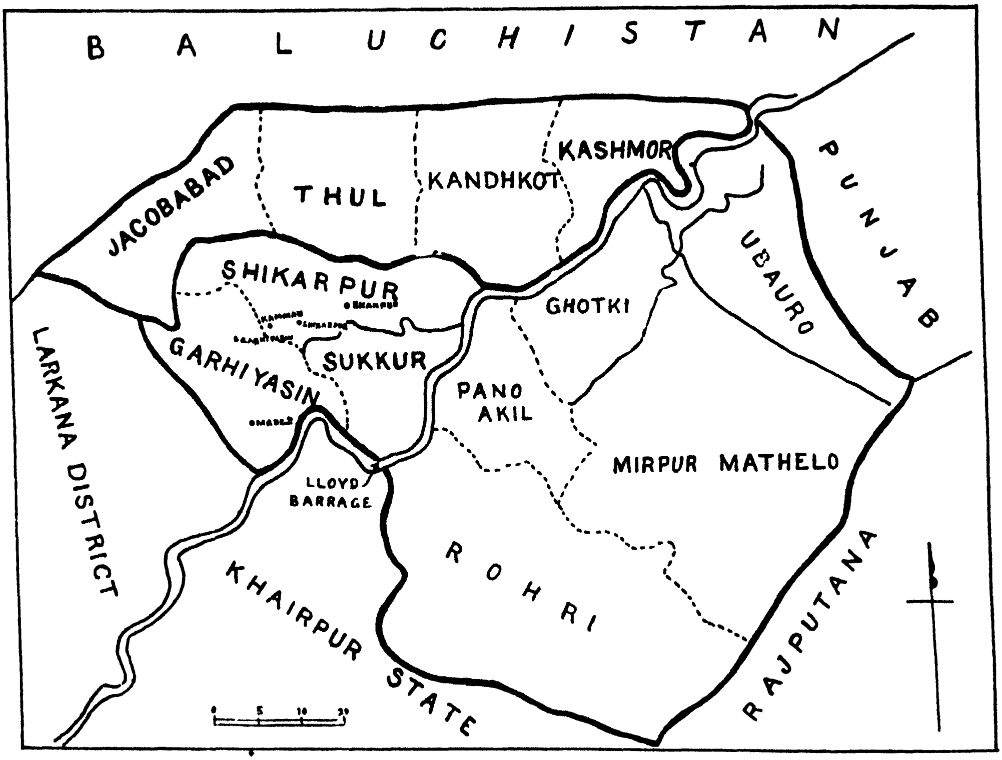
which occurred during the eight months immediately following the epidemic period.

For reasons which we discussed in detail, we formed the opinion that the rise in the B. T. parasite rate and in the spleen rate observed in August 1930 was due to the occurrence of delayed primary attacks or relapses ('recurrences') of benign tertian malaria during the spring or early summer, resulting from infections acquired during the previous autumn.

A study of the figures recorded in various villages of Shikarpur and Garhi Yasin talukas showed that the general features of the epidemic were the same

MAP.

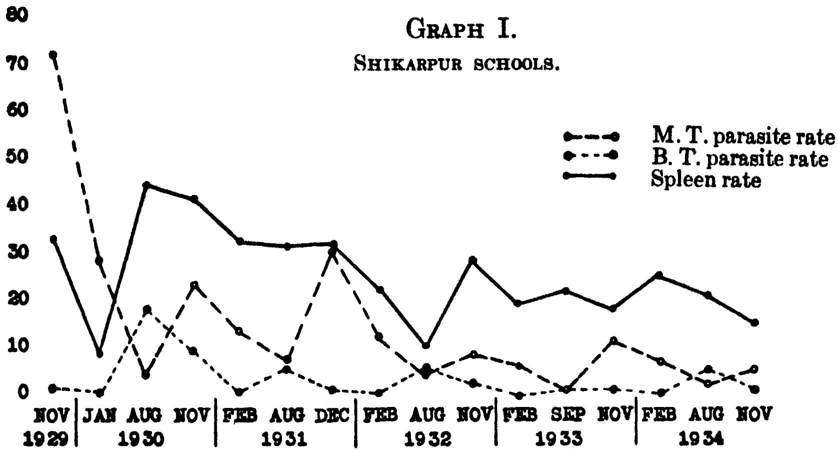
Map of Northern Sind.



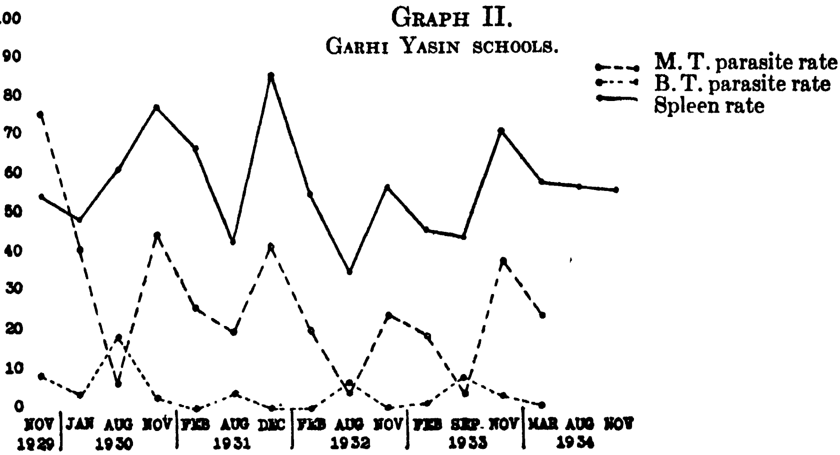
in all of them, although there were differences in the intensity with which it affected different localities.

The highest spleen rate recorded was 84 per cent, at Kamman, a village lying two miles west of Shikarpur, in August 1930. The highest M. T. parasite rate (94 per cent, 11th October, 1929), and the highest crescent rate (72 per cent, 25th October, 1929), were also recorded in this village. The highest B. T. parasite rate recorded was at Garhi Yasin, 10 miles south-west of Shikarpur, on 21st October, 1929. This had fallen to 4 per cent in January 1930, but had risen again to 19 per cent in August 1930, by which time the M. T. rate, which had been 76 per cent in November 1929, had fallen to 7 per cent. The

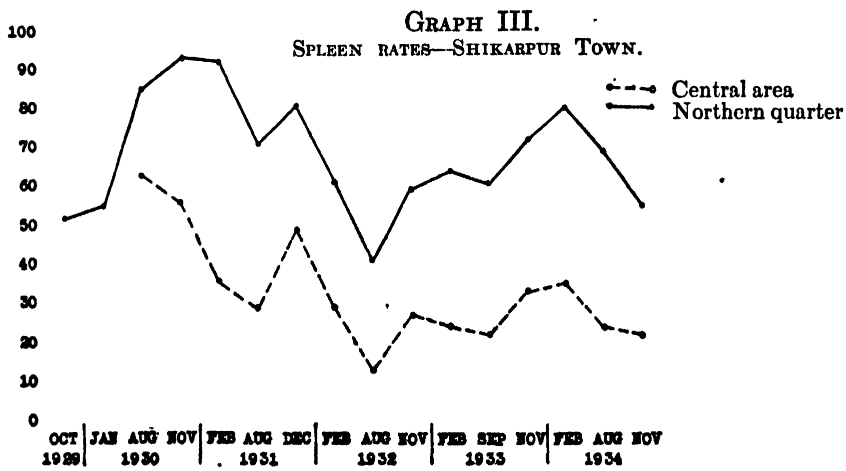
GRAPH I.
SHIKARPUR SCHOOLS.



GRAPH II.
GARHI YASIN SCHOOLS.



GRAPH III.
SPLEEN RATES—SHIKARPUR TOWN.



figures just quoted for Garhi Yasin resemble very closely those recorded in the Shikarpur schools at the same period.

The results of spleen and blood examinations made among the children of Shikarpur City and certain other localities in Shikarpur and Garhi Yasin talukas during the five-year period following the regional epidemic of 1929 are given in Appendices C and D, and in Graphs I, II and III. Observations were made three times each year, (*a*) immediately before the commencement of the annual malaria season, (*b*) during the malaria season, and (*c*) shortly after the end of the malaria season. The data collected suggest that in each malaria season the same general course of events takes place as in a regional epidemic, although on a much smaller scale.

Immediately before the malaria season crescents were extremely rare. Out of 2,000 blood films examined in August or the first week of September during the period 1930 to 1934, the total number of those in which crescents were found was 22 (1·1 per cent). At this period the M. T. parasite rate was always very low, whilst the B. T. rate was considerably higher than at the time of the autumn and winter observations, being frequently a good deal higher than the M. T. rate. This feature is well shown in Graphs I and II, which refer to examinations made among school children at Shikarpur and Garhi Yasin respectively.

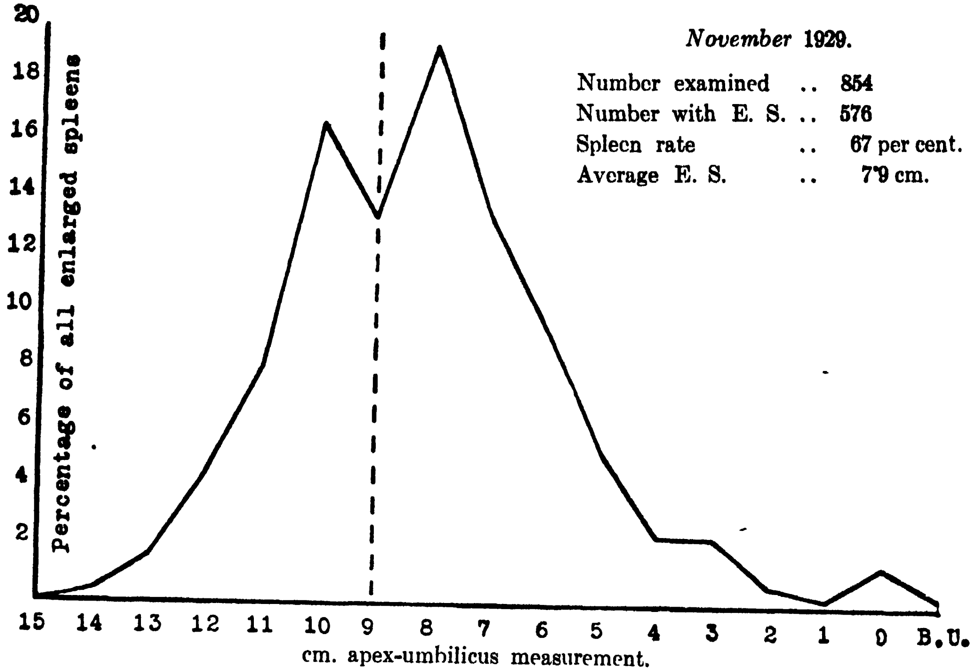
In the second series of observations, made each year in November or early December, towards the close of the malaria season, the M. T. parasite rate was fairly high, sometimes over 40 per cent (Garhi Yasin and Kamman, 1931; Madeji and Dhakkan, 1932; Khanpur, 1933). The crescent rate was also raised; this was especially noticeable in November 1933, when the crescent rate was 24 per cent in Khanpur, 20 per cent in Garhi Yasin, 15 per cent in Madeji and Dhakkan, 12 per cent in Kamman, and 5 per cent in the schools of Shikarpur City. At this period the B. T. parasite rate each year was everywhere very low.

In the third series of observations, made in February each year, the M. T. parasite rate had fallen considerably, crescents were generally rare, and the B. T. rate was also very low. In the case of observations carried out in the villages in the first week of March 1934, however, the B. T. rate had evidently begun to rise.

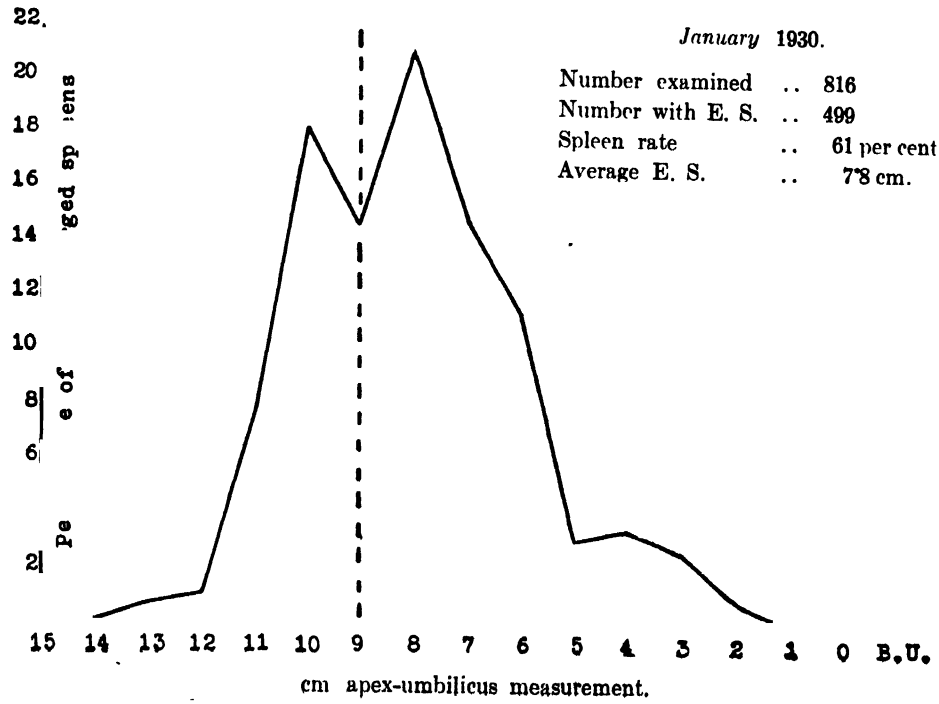
It thus appears that the annual malaria season in this part of Sind is in the main a mild replica of the great regional epidemics. The chief parasite concerned is *P. falciparum*, crescents are very rare immediately before the commencement of the epidemic, but relatively abundant at its height. There are a number of B. T. infections at the commencement of the malaria season, but the B. T. parasite rate declines almost to zero towards its end. On the other hand, a number of B. T. cases occur in the spring or early summer, and these we consider to be chiefly (perhaps exclusively) the results of infections acquired during the previous autumn.

The results of spleen examinations of street children in different quarters of Shikarpur City made during the five-year period following the epidemic are given in Appendix E. From these figures it will be seen that the incidence of malaria varied widely in intensity in different parts of the city, the spleen rates being particularly high in the northern sections. The combined rates for the latter area, and also the combined rates for the more central portions of the

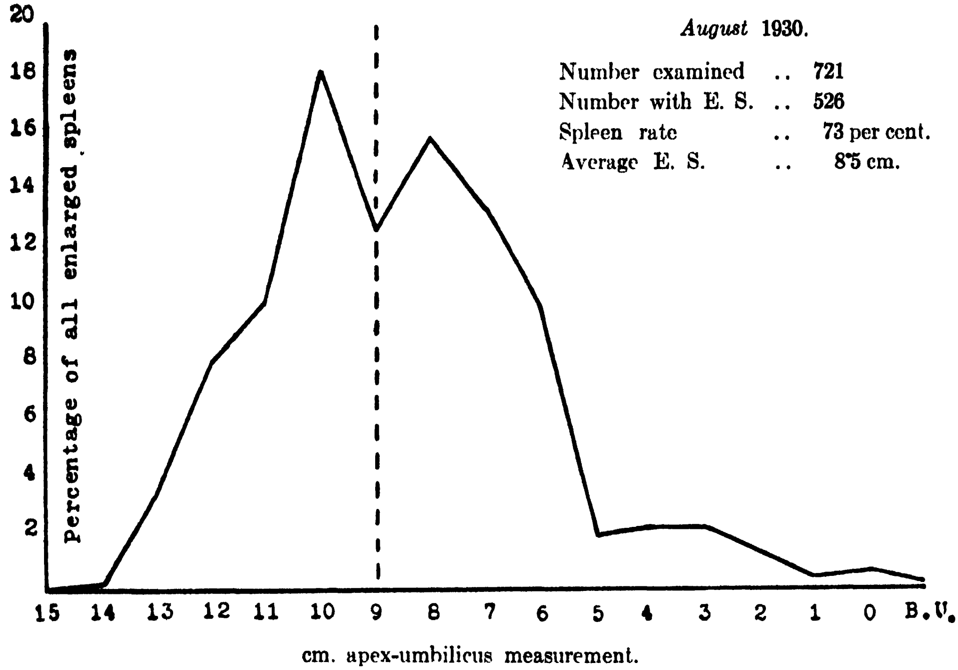
GRAPH IV.



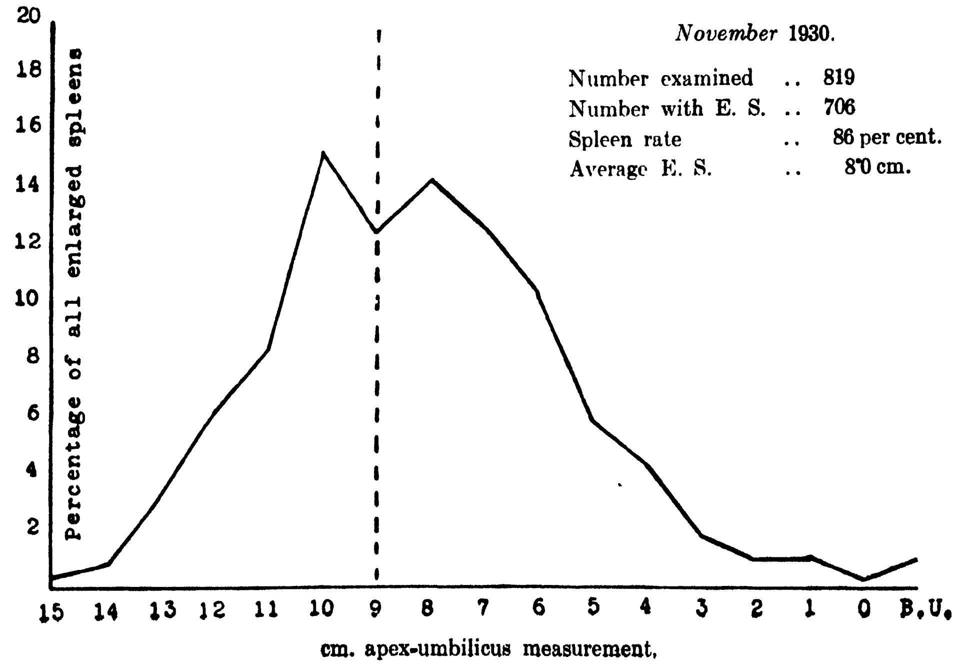
GRAPH V.



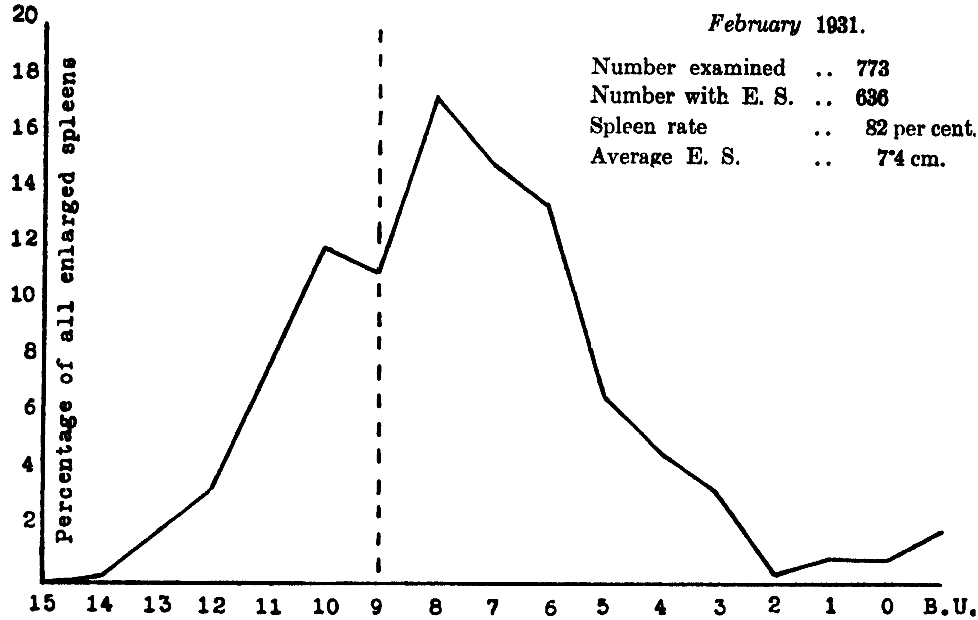
GRAPH VI.



GRAPH VII.

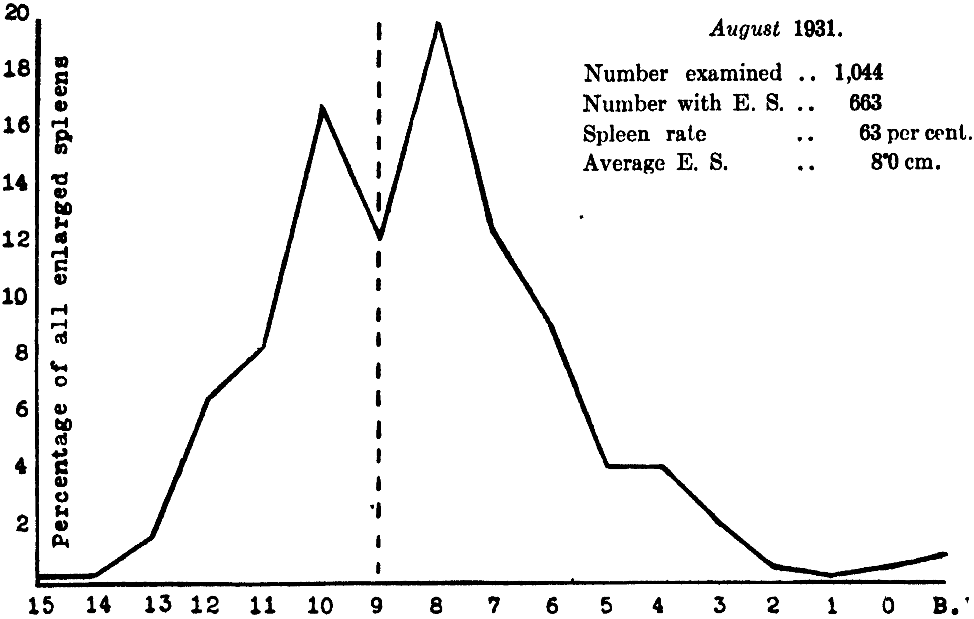


GRAPH VIII.



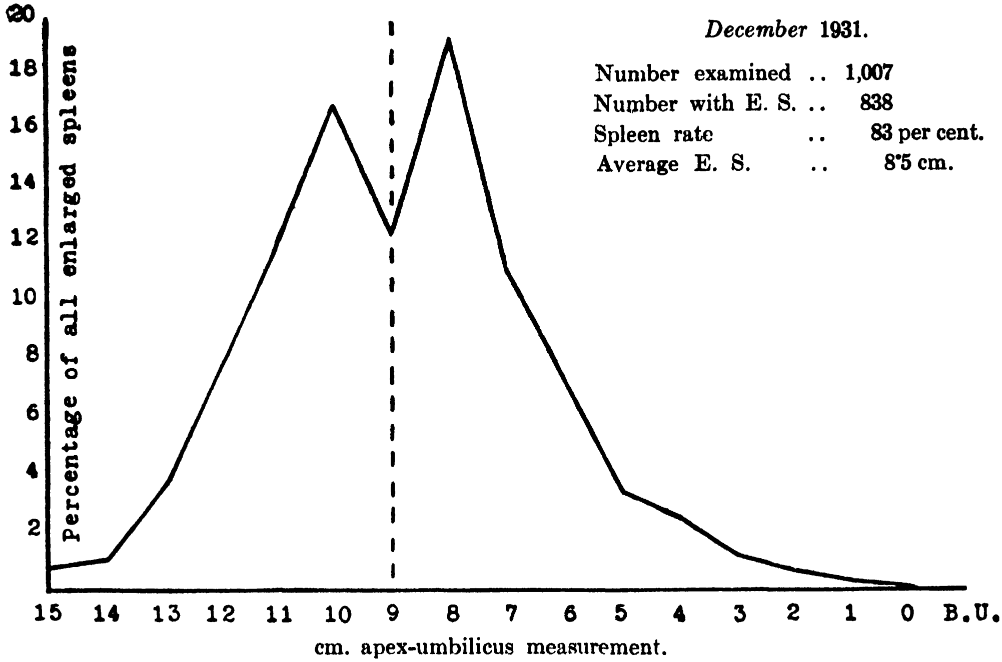
cm. apex-umbilicus measurement.

GRAPH IX.

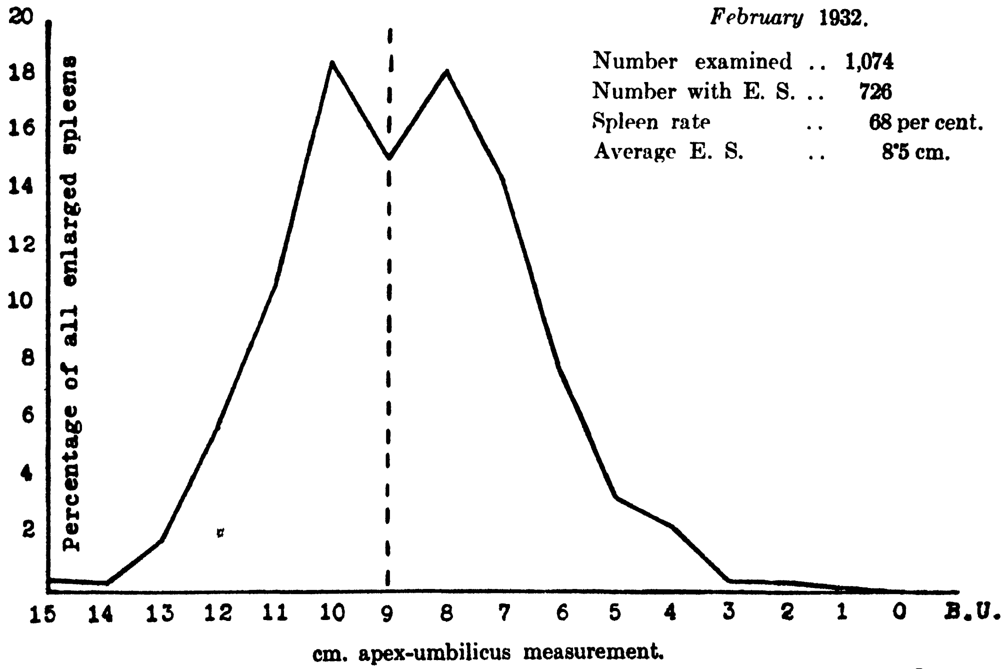


cm. apex-umbilicus measurement.

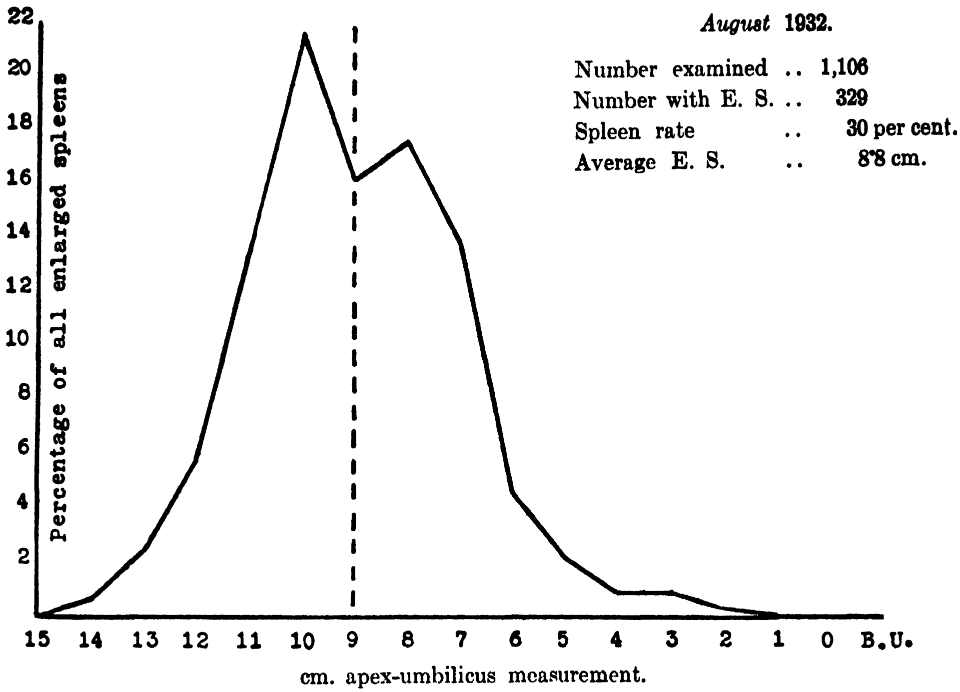
GRAPH X.



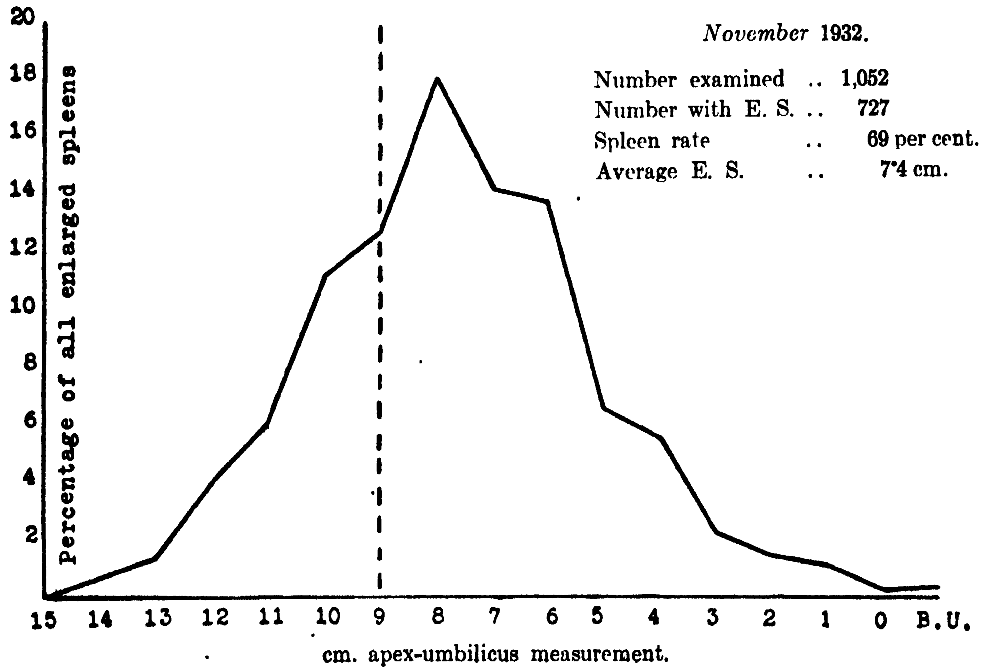
GRAPH XI.



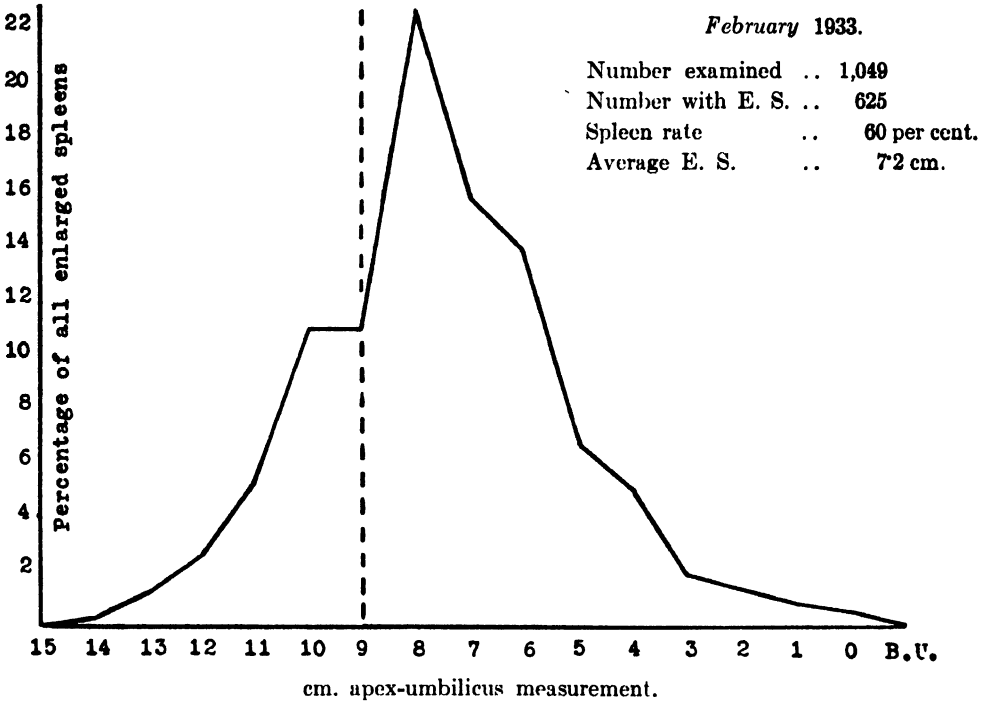
GRAPH XII.



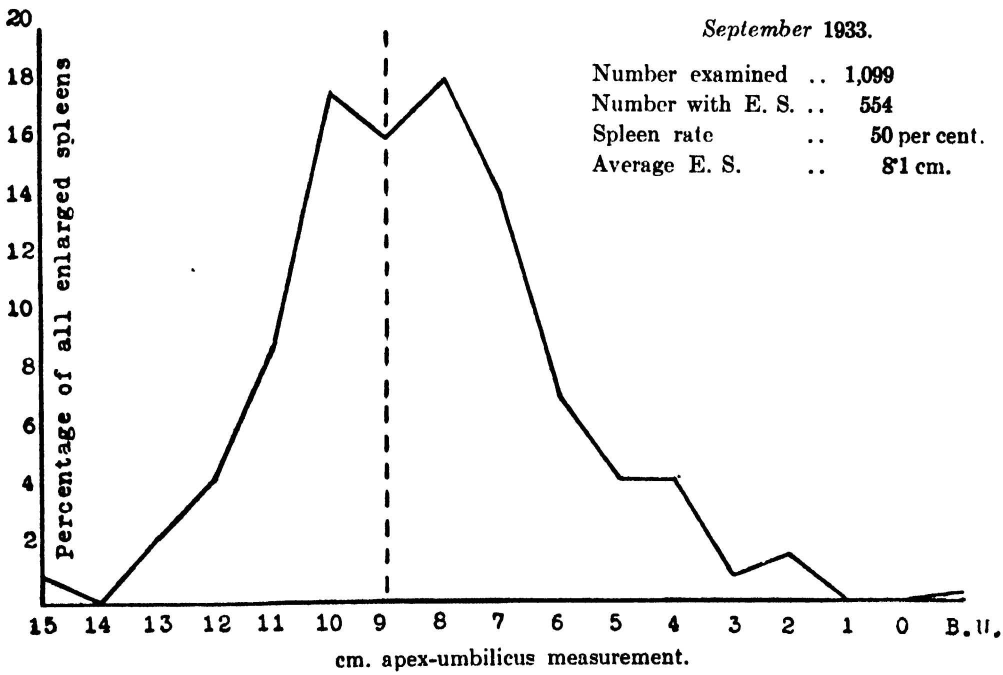
GRAPH XIII.



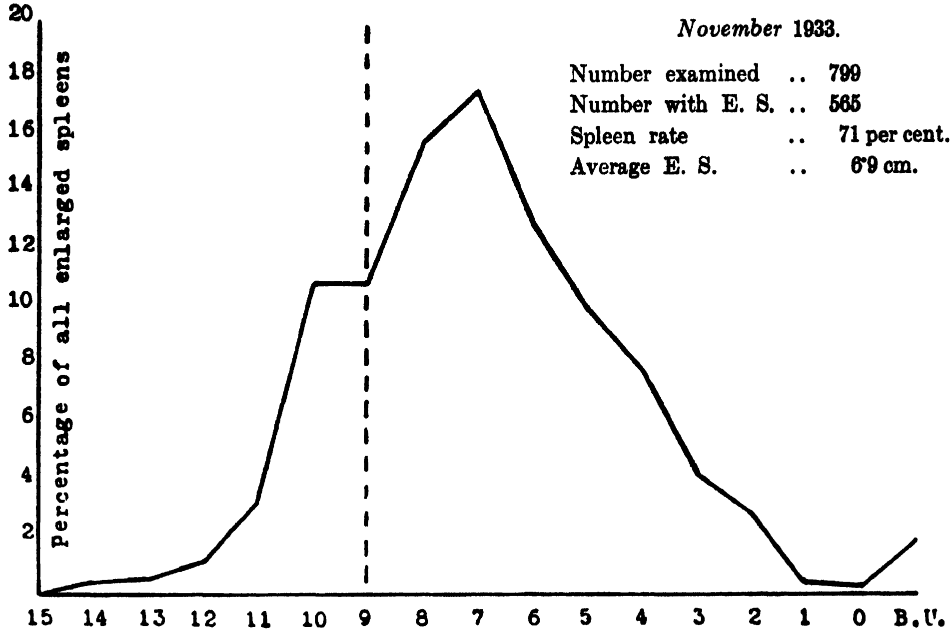
GRAPH XIV.



GRAPH XV.

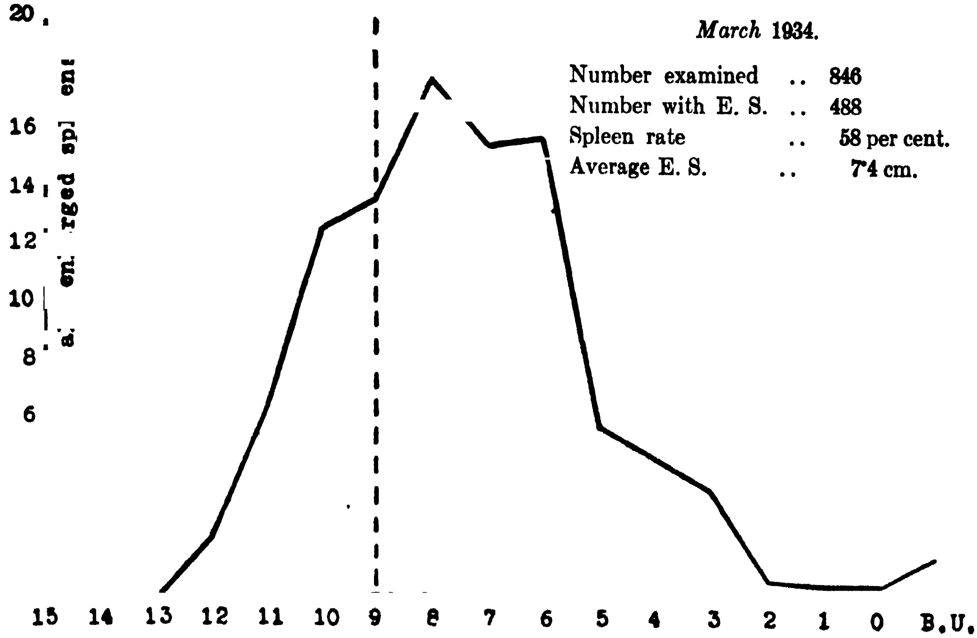


GRAPH XVI.



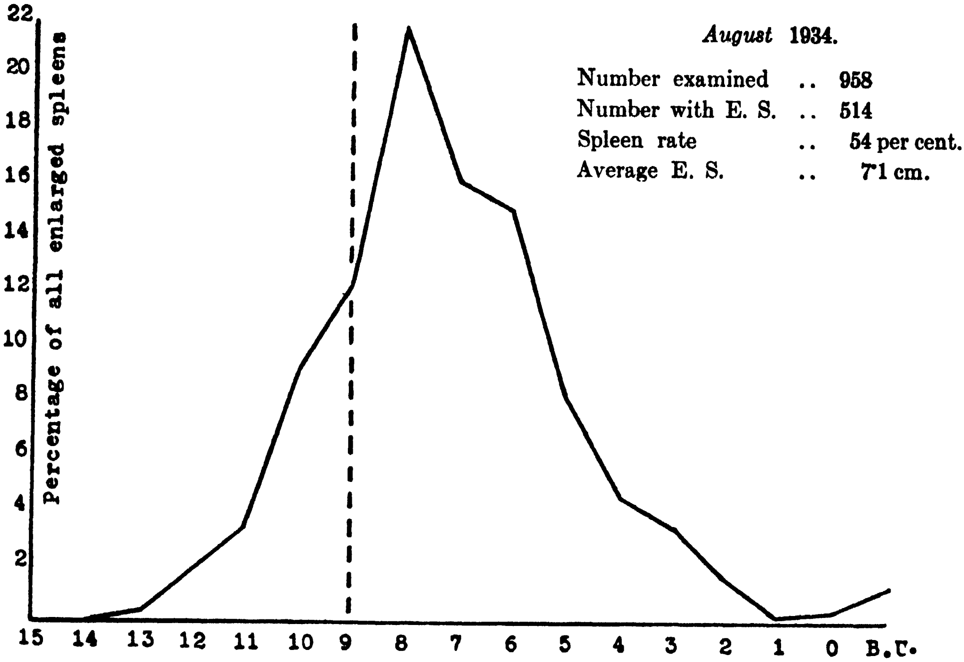
cm. apex-umbilicus measurement.

GRAPH XVII.



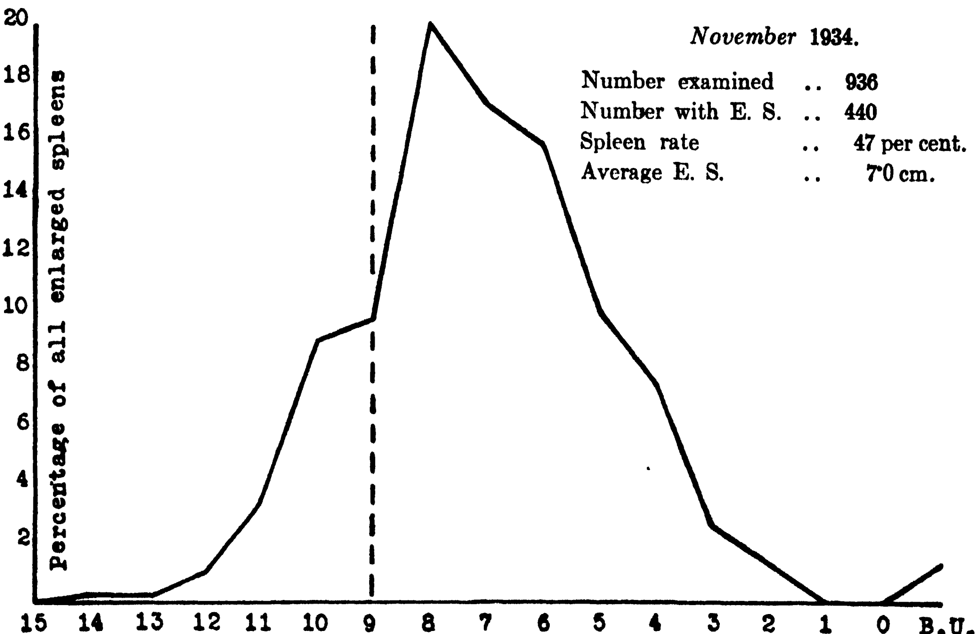
cm. apex-umbilicus measurement.

GRAPH XVIII.



cm. apex-umbilicus measurement.

GRAPH XIX.



cm. apex-umbilicus measurement.

city are shown separately in Graph III. The curve in each case shows the same general trend, but the much greater prevalence of malaria in the northern part of the city is well brought out.

The frequency distribution of spleen measurements recorded in certain localities in Shikarpur and Garhi Yasin talukas at various periods from 1929 to 1934 is shown in Graphs IV to XIX. The broken vertical line drawn at the 9 cm. mark in each graph has been so placed in order that alterations in the type of the curve may be more readily appreciated. It will be noted that in no instance is the peak of the curve situated at 9 cm. According to Macdonald (1931), spleens projecting to within approximately 10 cm. from the umbilicus represent either a recent active infection or a chronic quiescent infection, whereas those projecting to within 8 to 6 cm. from the umbilicus represent re-infections or relapses in those long infected.

In our former paper we showed that at the seventh week of the epidemic the curve representing the frequency distribution of spleen measurements among children in Shikarpur City was unimodal, but that it afterwards became bimodal, the second peak becoming more and more pronounced until by the thirteenth week it had become slightly higher than the first. The first peak represents spleens of 10 cm. measurement, the second, spleens of 8 cm. We ascribed the appearance of the second peak chiefly to the occurrence of a large number of early relapses of M. T. infections. This character is shown in Graphs IV and V, which refer to observations made in November 1929 and January 1930.

In Graph VI (August 1930) the same two peaks are shown, but the first is now higher than the second, probably due to a number of benign tertian attacks occurring in the spring and early summer.

In Graph VII (November 1930) the two peaks are almost equal again, whilst in February 1931, at the end of the malaria season, there is once more a predominance of larger spleens. This is a feature of all the observations made at this time of the year.

The results of our spleen and blood examinations indicate that the malaria season of 1933 was a particularly severe one, and it is interesting to compare the frequency distribution of enlarged spleens at the end of this season (Graphs XVI and XVII) with that recorded at the same periods in 1929-1930 (Graphs IV and V). The predominance of 8 and 7 cm. spleens in November 1933, and of 8, 7 and 6 cm. spleens in March 1934 is very striking. We consider that the difference shown between the spleen measurements of 1929-30 and of 1933-34 is due to the fact that in the former case the epidemic fell on a population which possessed little or no immunity to malaria, whereas in 1933 the level of communal immunity was comparatively high.

A COMPARISON BETWEEN THE SIND EPIDEMIC OF 1929-30 AND THE CEYLON EPIDEMIC OF 1934-35.

The great regional epidemic of malaria which occurred in Ceylon in 1934-35 exhibited many features in common with the Sind epidemic of 1929-30. It is true that the Ceylon epidemic was preceded by unusual drought, and the Sind epidemic by excessive rainfall; but in each case the effect was the same, *i.e.*, the production of unusually favourable conditions for the propagation, longevity

and activity of *A. culicifacies*. There was in each case an enormous numerical increase in this species, and a high infection rate, as shown by dissections. In each case the epidemic occurred among a population in which the communal immunity to malaria was at a low level. Economic conditions were unfavourable in both instances, in Ceylon on account of the failure of the crops from drought, in Northern Sind on account of the dislocation of trade and economic distress brought about by an epidemic of cholera and extensive floods which resulted in widespread destruction of property and cattle.

In the Sind epidemic, *P. falciparum* was the chief species of malaria parasite concerned, but there were a number of benign tertian infections in the first few weeks. In Ceylon, the B. T. parasite played a predominant part during the early stages of the epidemic, but later on it gave place to the M. T. parasite. It seems that the same course of events took place in each case as regards the relative prevalence of malaria parasites, except that in Ceylon the benign tertian parasite apparently played a greater part.

A feature of the Ceylon epidemic which is of particular interest to us was the occurrence of a second wave of morbidity in the spring of 1935, caused chiefly, if not entirely, by benign tertian infections. Gill (1936) states 'I assumed, *in accordance with Indian experience**, that there would be no second wave'. But, as we pointed out in our former paper (Covell and Baily, 1932), a prominent feature of the Sind epidemic was the occurrence of a large number of malaria cases in the following spring, at a time when climatic conditions were highly unfavourable for transmission. The evidence for this was the very marked increase in the spleen rates recorded throughout the epidemic area in the August following the epidemic, as compared with the rates recorded at the end of the autumnal epidemic period. At the same time it was found that there was a great increase in the B. T. parasite rate, which had fallen almost to zero in the preceding January.

Following the views expressed by James (1931) we attributed these results to the occurrence of a number of delayed primary attacks or recurrences of benign tertian malaria in the spring and early summer, resulting from infections acquired during the previous autumn. Since there was a predominance of benign tertian infections in the early stages of the Ceylon epidemic, the advent of a second wave of malaria in the following spring, due to delayed primary attacks or recurrences of benign tertian infections acquired during the previous autumn is precisely what we would have expected.

In the same paper, Gill put forward the hypothesis that the first rise in the morbidity curve at the commencement of the Ceylon epidemic was due to an 'epidemic of relapses'. By this he explained the absence of any appreciable increase in mortality among the children during the first four weeks of the epidemic, and the sudden and simultaneous onset of the epidemic over wide areas. Commenting on our findings in the case of Sind, he gave it as his opinion that these also were in accordance with what would be expected on the basis of his interpretation of the happenings in Ceylon.

It appears to us that the absence of any appreciable increase in mortality in the early stages of the epidemic might equally well be explained by the fact that the majority of the earlier infections were due to *P. vivax*, and therefore

* The italics are ours.

would not be likely to cause any great rise in mortality. Another explanation (put forward by Sir Rickard Christophers during the discussion on Gill's paper) is that the mildness of the earlier cases might be the result of numerically poorer infections in anophelines. Further, it seems to us most unlikely that an 'epidemic of relapses' could occur among a population in which the spleen rate immediately before the epidemic was so low (in the case of Sind, many of the villages which suffered very severely from the epidemic showed spleen rates of less than 5 per cent prior to its commencement). In the first place, an 'epidemic of relapses' surely presupposes a previous epidemic of primary attacks, and in the second place, as James and his collaborators have shown, the occurrence of relapses is not dependent on season, climate, humidity or any other environmental factor which has been thought from time to time to provoke relapse.

We consider that the origin of both these epidemics may be adequately explained by the sudden production of conditions unusually favourable to the propagation, longevity and activity of *A. culicifacies* in an area inhabited by a population in whom the communal immunity to malaria is at a low level. As James (1935) has pointed out, lack of immunity in the population at risk is the first requirement for the production of heavily infected mosquitoes. The result of infection occurring in non-immune persons is that gametocytes are produced more frequently and in far greater numbers than in those who possess some degree of immunity, and therefore the greater is the number of cases which are good infectors of anophelines. The introduction among such a community of enormous numbers of an efficient malaria-carrying anopheline species, such as *A. culicifacies* is known to be, under climatic conditions eminently favourable for its biological requirements, appears to us to be the one essential factor needed to precipitate a regional epidemic of malaria.

SUMMARY.

(1) An account is given of observations carried out in certain localities in Northern Sind during the period 1930 to 1934, *i.e.*, the five years immediately following the regional malaria epidemic of 1929.

(2) In certain localities spleen rates have declined approximately to their inter-epidemic level, but in a large number of cases this has not occurred, and the incidence of malaria remains very high.

(3) We consider that the maintenance of this high level of malaria incidence is largely attributable to conditions produced, directly or indirectly, by the operation of the Lloyd Barrage Scheme.

(4) The course of events during the five-year period under review suggests that each annual malaria season is a replica in a mild form of the regional epidemics which occur at intervals of approximately 10 years in Sind.

(5) A comparison is drawn between the Sind epidemic of 1929-30 and the Ceylon epidemic of 1934-35. It is considered that the course of events in each case was essentially the same, the precipitating cause being the sudden production of conditions unusually favourable for the propagation, longevity and activity of *A. culicifacies* in an area inhabited by a non-immune population. We disagree entirely with the view which has been put forward that in either case the first wave of morbidity might be due to the occurrence of an 'epidemic of relapses'.

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APPENDIX A.

Annual rainfall in inches recorded in the headquarter towns of the talukas of the Upper Sind Frontier and Sukkur districts for the years 1930 *to* 1934.

	1930	1931	1932	1933	1934
UPPER SIND FRONTIER DISTRICT.					
Jacobabad ..	2·36	0·01	4·86	5·10	3·11
Thul ..	1·21	0·75	2·46	5·87	2·76
Kandhkot ..	0·71	1·69	1·74	4·53	0·28
Kashmor ..	1·24	0·66	2·33	5·02	0·34
SUKKUR DISTRICT.					
Sukkur ..	0·84	0·20	3·09	5·89	1·10
Garhi Yasin ..	2·22	0·22	2·08	6·19	1·16
Shikarpur ..	2·93	0·64	2·44	3·32	..
Pano Akil ..	2·66	0·13	6·70	9·85	0·69
Ghotki ..	0·91	0·31	4·03	8·66	0·68
Ubauro ..	4·47	2·84	6·49	8·34	..
Mirpur Mathelo	1·79	0·88	7·42	12·65	0·47
Rohri ..	0·79	0·11	2·20	6·35	0·56

APPENDIX B.

Results of spleen examinations among children in Northern Sind, (a) before the regional epidemic of **1929**, *(b) immediately after the epidemic, and (c) five years after the epidemic.*

Locality.	A.			B.			C.		
	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.	Date.	Number examined.	Spleen rate.
UPPER SIND FRONTIER DISTRICT.									
Kashmor Taluka.									
Kashmor ..	i.28	62	11	x.30	111	82	xi.34	200	24
Gulam Mohd	i.28	35	11	x.30	30	73	xi.34	43	14
Kandhkot Taluka.									
Kandhkot ..	i.28	92	28	ix.30	201	84	x.34	235	40
	xi.28	204	10						
Haybat ..	i.28	39	26	ix.30	58	88	x.34	48	50
	xi.28	70	6						
Dari ..	xi.28	110	21	ix.30	100	92	x.34	78	47
Ghauspur ..	xi.28	178	63	ix.30	120	92	x 34	130	62
Thul Taluka.									
Mir Hasan ..	i.28	27	33	ix.30	53	83	xi.34	39	46
Thul ..	i.28	66	24	ix.30	181	87	xi.34	180	53
Jacobabad Taluka.									
Jacobabad ..	i.28	100	17	x.30	347	65	x.34	420	21
Jatohi ..	i.28	25	32	x.30	55	89	x.34	43	9
SUKKUR DISTRICT.									
Sukkur Taluka.									
Punjabi ..	iv.27	25	20	x.30	29	93	x.34	65	60
Rahuja ..	iv.27	22	4	x.30	41	88	x.34	50	64
Abad ..	iv.27	40	0	x.30	104	86	x 34	100	49
Arain ..	iv.27	62	8	x.30	63	88	x.34	120	62
Shahpur ..	iv.27	15	0	x.30	24	96	x.34	50	76
Old Sukkur ..	iv.27	207	22	x.30	270	80	x.34	281	33
Rohri Taluka.									
Miani ..	iv.27	26	38	x.30	48	91	x 34	60	78
Bichanji ..	iv.27	128	28	x.30	60	87	x.34	90	77
Kassim ..	iv.27	106	5	x.30	60	83	x.34	70	79
Jahan Khan ..	iv.27	31	18	x.30	52	90	x.34	60	82
Gosarji ..	iv.27	25	0	x.30	90	79	x.34	115	72
Lakhi ..	iv.27	103	4	x.30	150	93	x.34	125	81
Bagarji ..	iv.27	87	6	x.30	121	76	x.34	150	45
Dodo Kot ..	iv.27	25	8	x.30	24	87	x.34	25	76
Kandra ..	iv.27	160	2	x.30	112	60	x.34	205	70
Pano Akil Taluka.									
Pano Akil ..	x.28	120	12	x.30	70	68	ix.34	205	30
Pitafi ..	x.28	20	10	x.30	21	57	ix.34	39	56
Url and Jani Jo	x.28	61	28	x.30	41	90	ix.34	48	44
Shahpur ..	x.28	44	27	x.30	10	70	ix.34	27	63
Sadhuja ..	x.28	36	25	x.30	75	91	ix.34	55	82
Sawai Kalwar	x.28	52	25	x.30	28	68	ix.34	45	33

APPENDIX C.

Results of spleen and blood examinations among children in the schools of Shikarpur town, Shikarpur taluka, during the years 1929 to 1934.

Date.	Number examined for enlarged spleen.	Percentage found with enlarged spleen.	A-U measurement of average enlarged spleen.*	Number of bloods examined.	Percentage found with M. T. parasites.	Percentage found with asexual M. T. parasites.	Average positive asexual M. T. count per c.mm. of blood.	Percentage found with crescents	Average positive crescent count per c mm. of blood.	Percentage found with B. T parasites.	Average positive B. T. parasite count per c.mm. of blood.
1929.											
27. viii ..	205	1·5	11·3	88	16	16	364	0	0	11	1,950
10. x ..	161	17	9·2	100	42	41	1,191	2	420	27	5,214
17. x ..	164	20	10·0	100	42	38	2,806	5	428	16	5,636
24. x ..	180	27	9·0	99	69	36	1,090	55	682	14	900
29. x ..	..	..	..	100	67	32	247	49	308	11	180
25. xi ..	310	34	8·8	90	73	52	2,284	41	625	2	110
1930.											
15. i ..	92	9	9·4	75	29	29	424	1	80	1	80
26. viii ..	414	45	9·8	180	5	5	351	1	..	19	384
3. xi ..	564	42	9·0	80	24	22	1,012	1	120	10	973
1931.											
23. ii ..	660	33	8·3	100	14	14	528	0	0	1	460
29. viii ..	562	32	10·0	50	8	8	280	0	0	6	2,109
8. xii ..	805	32	9·7	100	31	31	368	0	0	2	330
1932.											
11. ii ..	889	23	9·8	75	13	13	346	0	0	1	340
26. viii ..	900	11	10·6	340	5	4	393	1	25	6	118
28. xi ..	800	29	9·0	349	9	8	752	1	625	3	673
1933.											
21. ii ..	795	20	9·5	300	7	7	345	0	0	0·3	120
4. ix ..	741	23	9·1	400	2	2	240	0	0	2	308
6. xi ..	800	19	8·2	400	12	8	1,152	5	175	2	475
1934.											
21. ii ..	825	26	8·0	400	8	6	722	2	63	1	45
8. viii ..	796	22	8·3	250	3	2	993	1	100	6	313
25. xi ..	970	16	8·6	250	6	6	51	1	550	2	135

* Measurement in centimetres from apex of spleen to umbilicus.

APPENDIX D.

TABLE I.

Results of spleen and blood examinations among children in Khanpur, Shikarpur taluka, during the years 1929 *to* 1934.

Date.	Number examined for enlarged spleen.	Percentage found with enlarged spleen.	A-U measurement of average enlarged spleen.*	Number of bloods examined.	Percentage found with M. T. parasites.	Percentage found with asexual M. T. parasites.	Average positive asexual M. T. count per c.mm. of blood.	Percentage found with crescents.	Average positive crescent count per c.mm. of blood.	Percentage found with B. T. parasites.	Average positive B. T. parasite count per c.mm. of blood.
1929.											
15. x ..	175	36	9·7	100	91	90	4,666	27	909	0	0
22. x ..	172	34	9·0	100	75	49	1,254	50	1,724	1	6,400
30. x ..	204	41	8·4	80	81	74	2,547	22	140	2	240
5. xi ..	168	56	8·5	98	73	63	1,329	26	399	9	44,729
27. xi ..	208	58	8·0	99	80	76	2,810	11	162	1	500
1930.											
18. i ..	182	58	7·6	100	68	59	1,139	9	242	1	140
1931.											
26. ii ..	240	93	6·8	20	15	15	387	0	0	0	0
28. viii ..	225	67	7·5	..	..	..	..	..	..	..	..
22. xii ..	250	86	8·7	..	..	..	..	..	..	..	..
1932.											
12. ii ..	180	76	8·2	50	26	26	828	0	0	2	180
27. viii ..	240	35	8·6	90	3	2	30	1	20	12	58
28. xi ..	226	54	8·2	60	15	12	351	3	100	0	0
1933.											
25. ii ..	187	45	7·6	40	7	7	93	0	0	0	0
1. ix ..	268	37	8·5	100	7	7	223	0	0	0	0
9. xi ..	218	59	7·3	50	42	26	2,680	24	673	0	0
1934.											
5. iii ..	210	47	7·7	100	14	13	637	1	540	1	20
11. viii ..	263	37	7·5	..	..	..	..	..	..	..	..
27. xi ..	287	38	7·8	..	..	..	..	..	..	..	..

* Measurement in centimetres from apex of spleen to umbilicus.

Table II.

Results of spleen and blood examinations among children in Kamman, Shikarpur taluka, during the years 1929 *to* 1934.

Date.	Number examined for enlarged spleen.	Percentage found with enlarged spleen.	A-U measurement of average enlarged spleen.*	Number of bloods examined.	Percentage found with M. T. parasites.	Percentage found with asexual M. T. parasites.	Average positive asexual M. T. count per c.mm. of blood.	Percentage found with crescents	Average positive crescent count per c.mm. of blood.	Percentage found with B. T. parasites.	Average positive B. T. parasite count per c.mm. of blood.
1929.											
11. x ..	253	71	8·5	146	94	91	13,916	20	3,167	4	13,243
18. x ..	199	79	9·1	74	84	80	6,899	40	2,170	8	8,940
25. x ..	224	74	9·2	65	78	57	1,148	72	786	6	4,360
31. x ..	229	61	8·0	45	84	78	1,537	27	712	2	3,840
26. xi ..	197	83	8·1	50	86	84	4,519	10	104	2	1,120
1930.											
16. i ..	212	74	7·9	..	..	..	..	..	..	..	..
28. viii ..	173	84	9·0	90	58	58	216	0	0	4	385
5. xi ..	155	95	7·3	20	60	40	1,432	20	345	0	0
1931.											
25. ii ..	203	94	7·2	20	20	20	355	0	0	0	0
26. viii ..	244	74	8·0	20	35	35	820	0	0	15	1,246
23. xii ..	170	92	7·9	25	48	48	762	0	0	0	0
1932.											
15. ii ..	215	89	8·3	25	20	16	1,030	4	180	0	0
25. viii ..	165	47	8·4	..	..	..	..	..	..	..	..
30. xi ..	183	73	7·0	..	..	..	..	..	..	..	..
1933.											
24. ii ..	211	53	6·7	50	10	10	2,008	0	0	0	0
5. ix ..	129	52	8·3	50	0	0	0	0	0	4	480
11. xi ..	139	80	6·2	25	32	28	1,967	12	80	0	0
1934.											
6. iii ..	123	76	7·8	40	12	12	144	0	0	2	20
9. viii ..	137	67	7·0	..	..	..	..	..	..	..	..
28. xi ..	191	57	6·9	..	..	..	..	..	..	..	..

* Measurement in centimetres from apex of spleen to umbilicus.

Table III.

Results of spleen and blood examinations among children in Garhi Yasin, Garhi Yasin taluka, during the years 1929 *to* 1934.

Date.	Number examined for enlarged spleen.	Percentage found with enlarged spleen.	A-U measurement of average enlarged spleen.*	Number of bloods examined.	Percentage found with M. T. parasites.	Percentage found with asexual M. T. parasites.	Average positive asexual M. T. count per c.mm. of blood.	Percentage found with crescents.	Average positive crescent count per c mm. of blood.	Percentage found with B. T. parasites.	Average positive B. T. parasite count per c.mm. of blood.
1929.											
14. x ..	215	45	9·5	100	65	62	7,197	10	3,820	20	4,000
21. x ..	176	45	8·4	100	61	57	2,445	23	1,282	32	2,389
29. x .	206	44	9·4	100	68	46	952	53	281	11	381
4. xi ..	251	51	8·9	100	62	42	638	35	277	7	540
25. xi ..	164	55	7·9	99	76	72	2,137	29	522	9	1,677
1930.											
16. i ..	270	49	8·3	100	41	38	753	11	189	4	185
26. viii ..	337	62	9·0	100	7	4	75	3	40	19	387
4. xi ..	324	78	8·0	60	45	42	2,234	5	2,933	3	130
1931.											
23. ii ..	330	67	8·4	49	26	24	597	2	600	0	0
26. viii ..	330	43	8·5	25	20	20	368	0	0	4	1,120
9. xii ..	312	86	8·9	50	42	42	898	0	0	0	0
1932.											
13. ii ..	377	55	8·7	50	20	20	342	0	0	0	0
26. viii ..	302	35	9·0	100	4	4	100	0	0	7	69
29. xi ..	333	57	7·3	80	24	21	1,665	5	1,325	0	0
1933.											
24. ii ..	351	46	7·3	80	19	16	1,058	6	120	1	5,620
29. ix ..	341	44	8·5	99	4	4	250	0	0	8	772
8. xi ..	239	71	7·0	200	38	28	2,953	20	532	3	323
1934.											
6. iii ..	322	48	7·4	100	24	20	921	9	49	1	80
10. viii ..	340	47	7·2	..	..	..	..	..	..	..	..
29. xi ..	234	46	7·4	..	..	..	..	..	..	..	..

* Measurement in centimetres from apex of spleen to umbilicus.

Table IV.

Results of spleen and blood examinations among children in Madeji and Dhakkan, Garhi Yasin taluka, during the years 1929 *to* 1934.

Date.	Number examined for enlarged spleen.	Percentage found with enlarged spleen.	A-U measurement of average enlarged spleen.*	Number of bloods examined.	Percentage found with M. T. parasites.	Percentage found with asexual M. T. parasites.	Average positive asexual M. T. count per c.mm. of blood.	Percentage found with crescents.	Average positive crescent count per c.mm. of blood.	Percentage found with B. T. parasites.	Average positive B. T. parasite count per c.mm. of blood.
1929.											
16. x ..	210	62	9·2	99	86	81	7,945	29	1,016	24	5,207
23. x ..	131	63	9·0	99	81	54	2,523	60	831	13	5,969
30. x ..	339	65	8·1	73	77	63	913	45	302	4	4,667
6. xi ..	274	67	8·4	70	86	80	1,195	11	150	1	9,880
28. xi ..	285	71	7·6	100	68	65	2,814	6	617	1	560
1930.											
21. i ..	152	69	7·2	100	85	85	1,782	14	227	0	0
1. ix ..	211	83	7·4	60	45	42	182	3	20	2	20
31. x ..	340	90	8·6	..	..	..	..	..	..	..	..
1931.											
31. viii ..	245	78	7·9	25	44	44	713	0	0	4	280
7. xii ..	275	71	8·6	50	34	34	425	0	0	2	120
1932.											
16. ii ..	302	63	8·4	50	22	20	402	2	180	2	480
30. viii ..	399	32	7·3	100	2	2	660	0	0	10	234
2. xii ..	310	94	7·2	90	46	41	2,518	10	386	2	3,690
1933.											
24. ii ..	300	89	7·3	100	15	13	269	2	70	0	0
12. ix ..	361	66	7·8	100	12	11	880	2	630	1	220
10. xi ..	203	77	6·6	100	21	7	349	15	227	0	0
1934.											
7. iii ..	191	74	7·0	90	19	18	501	1	20	4	110
14. ix ..	218	75	6·5	..	..	..	..	..	..	..	..
26. xi ..	224	50	7·8	..	..	..	..	..	..	..	..

* Measurement in centimetres from apex of spleen to umbilicus.

APPENDIX E.

Results of spleen examinations among street children in different quarters of Shikarpur town, during the years 1930 to 1934.

Locality.	Number examined.	Number with enlarged spleen.	Spleen rate.	A-U measurement of average enlarged spleen.*
	29th to 31st August, 1930.			
Wadhu Market ..	128	92	72	8·4
Kiri South ..	41	35	85	9·6
Kiri Nawab Khan ..	44	38	86	7·6
Masandpur ..	66	50	76	8·8
Shaik Bungal Well ..	119	57	48	8·6
Sidik Mari ..	73	51	70	8·3
Nembhanpur ..	31	24	77	10·6
Total ..	502	347	69	8·8
	3rd to 5th November, 1930.			
Wadhu Market ..	99	61	62	8·4
Kiri South ..	44	40	91	8·8
Kiri Nawab Khan ..	52	50	96	7·0
Masandpur ..	50	35	70	10·5
Shaik Bungal Well ..	66	28	42	10·0
Sidik Mari ..	29	16	55	9·8
Nembhanpur ..	20	14	70	9·2
Total ..	360	244	68	8·8
	21st to 23rd February, 1931.			
Wadhu Market ..	96	36	37	9·1
Kiri South ..	41	38	93	8·2
Kiri Nawab Khan ..	53	49	92	8·6
Masandpur ..	52	26	50	8·9
Shaik Bungal Well ..	58	18	31	9·4
Sidik Mari ..	49	14	29	9·0
Nembhanpur ..	22	14	64	9·0
Total ..	371	195	52	8·8
	27th to 28th August, 1931.			
Wadhu Market ..	61	19	31	9·3
Kiri South ..	58	45	78	9·5
Kiri Nawab Khan ..	68	46	68	8·7
Masandpur ..	57	19	33	8·9
Shaik Bungal Well ..	61	11	18	9·7
Sidik Mari ..	60	23	38	10·4
Nembhanpur ..	32	14	44	9·2
Total ..	397	177	45	9·2

* Measurement in centimetres from apex of spleen to umbilicus.

APPENDIX E—*contd.*

Locality.	Number examined.	Number with enlarged spleen.	Spleen rate.	A-U measurement of average enlarged spleen.*
		8TH TO 11TH DECEMBER, 1931.		
Wadhu Market ..	85	51	60	9·6
Kiri South ..	45	34	76	9·9
Kiri Nawab Khan ..	80	68	85	8·0
Masandpur ..	110	61	55	9·2
Shaik Bungal Well ..	100	35	35	11·6
Sidik Mari ..	140	70	50	9·6
Nembhanpur ..	40	27	67	9·8
TOTAL ..	600	346	58	9·6
		11TH TO 14TH FEBRUARY, 1932.		
Wadhu Market ..	76	29	38	10·0
Kiri South ..	44	28	64	10·0
Kiri Nawab Khan ..	67	41	61	9·4
Masandpur ..	100	33	33	9·6
Shaik Bungal Well ..	90	30	33	10·5
Sidik Mari ..	106	20	19	9·5
Nembhanpur ..	40	18	45	9·7
TOTAL ..	523	199	38	9·7
		25TH TO 28TH AUGUST, 1932.		
Wadhu Market ..	79	7	9	10·2
Kiri South ..	52	21	40	10·3
Kiri Nawab Khan ..	75	33	44	8·3
Masandpur ..	101	14	14	7·8
Shaik Bungal Well ..	62	2	3	..
Sidik Mari ..	88	14	16	8·7
Nembhanpur ..	41	10	24	9·4
TOTAL ..	498	101	20	10·0
		28TH TO 30TH NOVEMBER, 1932.		
Wadhu Market ..	100	30	30	9·6
Kiri South ..	50	43	86	9·0
Kiri Nawab Khan ..	71	49	69	9·0
Masandpur ..	100	37	37	9·3
Shaik Bungal Well ..	100	18	18	12·4
Sidik Mari ..	90	26	29	9·3
Nembhanpur ..	40	21	52	9·7
TOTAL ..	551	224	41	9·6

* Measurement in centimetres from apex of spleen to umbilicus.

APPENDIX E—*contd.*

Locality.	Number examined.	Number with enlarged spleen.	Spleen rate.	A-U measurement of average enlarged spleen.*
		21ST TO 23RD FEBRUARY, 1933.		
Wadhu Market ..	105	26	25	9·0
Kiri South ..	60	41	68	9·0
Kiri Nawab Khan ..	75	47	63	9·4
Masandpur ..	120	40	33	9·7
Shaik Bungal Well ..	80	10	12	10·7
Sidik Mari ..	110	29	26	9·0
Nembhanpur ..	35	6	17	12·4
TOTAL ..	585	199	34	9·3
		4TH TO 7TH SEPTEMBER, 1933.		
Wadhu Market ..	115	32	28	10·0
Kiri South ..	60	39	65	10·0
Kiri Nawab Khan ..	83	50	60	9·5
Masandpur ..	110	20	18	10·4
Shaik Bungal Well ..	81	18	22	10·3
Sidik Mari ..	120	28	23	9·2
Nembhanpur ..	50	15	30	10·0
TOTAL ..	619	202	33	9·8
		6TH TO 8TH NOVEMBER, 1933.		
Wadhu Market ..	125	48	38	7·7
Kiri South ..	30	23	77	7·9
Kiri Nawab Khan ..	65	46	71	7·7
Masandpur ..	104	31	30	7·6
Shaik Bungal Well ..	100	35	35	9·5
Sidik Mari ..	80	25	31	8·7
Nembhanpur ..	35	22	63	8·2
TOTAL ..	539	230	43	8·0
		21ST TO 24TH FEBRUARY, 1934		
Wadhu Market ..	100	43	43	8·4
Kiri South ..	40	33	82	8·0
Kiri Nawab Khan ..	100	81	81	8·3
Masandpur ..	100	38	38	8·3
Shaik Bungal Well ..	100	35	35	8·6
Sidik Mari ..	100	27	27	9·0
Nembhanpur ..	40	25	57	8·8
TOTAL ..	580	280	48	8·6

* Measurement in centimetres from apex of spleen to umbilicus.

APPENDIX E—*concld.*

Locality.	Number examined.	Number with enlarged spleen.	Spleen rate.	A-U measurement of average enlarged spleen.*
	8TH TO 11TH AUGUST, 1934.			
Wadhu Market ..	140	40	29	9·2
Kiri South ..	65	44	67	8·3
Kiri Nawab Khan ..	70	51	73	8·0
Masandpur ..	130	31	24	9·0
Shaik Bungal Well ..	146	36	25	8·9
Sidik Mari ..	127	27	21	9·0
Nembhanpur ..	65	28	43	9·2
TOTAL ..	743	257	35	8·8
	25TH TO 28TH NOVEMBER, 1934.			
Wadhu Market ..	120	29	24	9·0
Kiri South ..	53	35	66	8·4
Kiri Nawab Khan ..	70	34	49	7·8
Masandpur ..	120	27	22	8·7
Shaik Bungal Well ..	125	18	14	9·4
Sidik Mari ..	120	37	31	9·4
Nembhanpur ..	60	19	32	9·8
TOTAL ..	668	199	30	8·9

* Measurement in centimetres from apex of spleen to umbilicus.

Records of the Malaria Survey of India, **6**, 3, *September*, 1936.

WILLIAMSON'S 'HERBAGE COVER' METHOD OF LARVAL CONTROL.

A PRELIMINARY NOTE ON SOME FIELD TRIALS.

BY

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[28th May, 1936.]

THE writer (Senior White, 1926) showed that a saline ammonia water content of 1 p.p.m. rendered water apparently unsuitable to the larvæ of carrier Anophelines. In a subsequent paper (Senior White, 1928), this work was extended and confirmed, though it was then shown that saline ammonia as such is almost certainly not directly concerned, but that the effect so measured is only the result of the inter-action of other, quite unknown, factors. Subsequently, the values obtained from work in Ceylon and in India were found to apply to the Neotropical *A. tarsimaculatus* by Beattie (1932). This writer's figures were collated and statistically analysed by Buxton (1934).

Williamson (1928) reviewed the earlier work and drew attention to the importance of these findings in regard to malaria control, but it was not until some years later that he was able to undertake experiments, first at Cameron Highlands, and later at Penang, with a view to bringing saline ammonia and other chemical factors artificially to values inhibiting the breeding of malaria-carrying Anophelines. His results appeared from time to time in an Agricultural Journal not likely to be seen by malaria workers, but these papers have recently been collected into a single publication (Williamson, 1935). In this paper he describes the method now to be reported on as follows :—

HERBAGE COVER.

'Another natural method may be specially mentioned here. It has only recently been tried, and is in consequence only known to a few, but it deserves wide and general testing. This is the method of Herbage Cover. Its operation is simplicity itself. Shallow water up to a few inches deep is covered with packed grass and herbage, or with the leaves of trees from rapidly growing scrub or jungle, with a few twigs intermixed, so as to form a brushwood drain,

should the water be running. This herbage is well trampled under foot until it forms an almost solid wall, a foot or more in height. The cover thus formed is long lasting, and, so far as observation has gone, it cannot be penetrated by egg-laying mosquitoes; it provides dense shade and in stagnant or slowly moving water, sufficiently concentrated rotting to prevent the breeding of malarial species. While inapplicable to rapidly running streams or steep ravines which discharge strong flushes of storm water, very little dislocation of the herbage occurs in ordinary hillfoot or other drains, if their lower ends are provided with a double row of stakes to keep the solid mass of vegetation in position. Some of the storm water flows under it, and the remainder makes its way over the top'.

The original paper must, however, be consulted for a full discussion of the method.

The first experiment made on these lines by the writer was on what is known as the 'North Nullah' at Theruvali Railway Station. This station is situated at about 800 ft. elevation, in the Jeypore Hills Agency Tracts (formerly in Madras, now in the new Province of Orissa). The station has been under malaria control, first as a construction camp, then as a regular railway station, since 1928. The nullah in question descends from the hills, crossing the railway at right angles. Upstream, west of the line, it runs in a deeply cut earth ravine overhung by poor 'Sal' forest mixed with secondary growth of other species. East of the line it emerges, though still in a deep ravine, into open cultivated land, chiefly devoted to dry crops, though the villagers make no attempt to divert its flow for irrigation of such rice land as there is in the immediate vicinity. It debouches, within protection limits, into a fair sized river, the Kedapara.

On survey, the nullah bred *A. maculatus, A. theobaldi, A. funestus* subspp., *A. culicifacies* and *A. vagus,* according to light incidence, the last two species being more prevalent in the open length east of the railway.

As usual, the first procedure in taking up such a nullah for control, was to clear from the bed all fallen trees, débris blocks, etc., and to canalise a narrow channel to facilitate oiling. This channel can be seen in Plate VII, fig. 1. The bed of the nullah is in places sand, in others, laterite. There are no boulders or true earth. As such nullahs are always subject to heavy spates during the rains, the cleaning and canalising has to be repeated every October. Before the present experiment was initiated it had already been cleaned up, and a few weeks' oiling done, in preparation for the malaria season 1935-36.

Packing was commenced late in October, and Williamson's directions were strictly followed, except that the packing was made about 3 feet deep. The plant used was mainly *Cleistanthus colinus* or *C. oblongifolius* (natural order Euphorbiaceæ) a large bush or small tree. Branches up to a finger breadth in diameter were lopped, and very roughly laid longitudinally to the axis of the nullah Retaining walls of sticks were placed at intervals (Plate VII, fig. 1), the final appearance being as in Plate VII, fig. 2.

For the first fortnight after packing, Anopheline breeding (species not noted), continued in the packed length, but this must have been sparse, or of innocuous species, for though October-November is the most malarious period in these hills, there was only one case of malaria at the station during these months. The Malaria Inspector for the Section noted that Anopheline breeding was at its maximum in the second week after packing was substituted for oiling,

but this may have been due to the after-effects of oiling in the first week. After a month an examination of the packed length showed Anopheline larvæ to be entirely absent, but a few Culicine larvæ were present. On a second examination six to seven weeks after packing, it was observed that the smell of the water as it emerged from the packing into the open channel below was like that of a septic tank latrine effluent, though it was perfectly limpid. The bottom of the channel in the open length was covered with a black sludge for some hundreds of feet, and long white fungal masses were waving in the current. Evidently the water was entirely deprived of oxygen. However, after some 400 to 500 yards in the open channel, re-aëration began to occur, marked by the usual patches of a Chlorophyceous alga on the sandy bottom. No particular Culicine breeding was noted, but adults were hovering over the packing, and a Syrphid fly, *Eristalis* sp., was breeding in the squashy mess. Immediately above the control limit, up to which packing was done, the nullah, in its natural débris-blocked bed, was breeding *A. maculatus* and *A. fluviatilis* as usual, indicating that a nearby repellent smell, provided that it did not emanate from the actual water sought, had no repulsive effect. Six weeks later, an enormous amount of Culicine breeding was found within the packing. From then onward regular breeding-out from larvæ and pupæ has been done, the results of which are shown in Table I.

TABLE I.

Breeding in North Nullah, Theruvali, under herbage packing.

Species.	23-1-36.	February 1936.	10-3-36.	26-3-36.	15-4-36.	7-5-36.
A. theobaldi	..	..	..	..	..	+
A. splendidus	..	.	..	..	..	+
A. culicifacies	..	..	..	..	..	+
A. jamesi	..	.	..	..	+	..
A. subpictus	..	..	..	..	+	+
C. fatigans	+	+	+	+	+	+
C. edwardsi	+	..	..	..	..	..
C. gelidus	..	+	+	+	+	..
C. fuscocephalus	..	+	..	..	..	+
C. malayi	+	..	..	..	..	..
C. minutissimus	..	..	..	+	+	..
C. bitaeniorhynchus	..	..	..	..	..	+
L fuscana	..	+	+	+	..	..
F. luzonensis	+	..	+	+	..	..
Uranotaenia sp.	+	..	..	..	+	..

This table shows that after six months the toxic substances leached from the herbage are entirely exhausted. *Spirogyra* is evidently growing on the twigs, as indicated by the presence of *C. bitaeniorhynchus*. The re-oxygenation of the water has allowed carrier Anophelines again to breed. Thus it may be taken that six months is the safe limit of packing with a single charge of, at any rate, *Cleistanthus*. [Whether other plants will last longer is a matter for further experiment.] However, as it was anticipated from the first that by the end of May the packing would be entirely washed out by the first monsoon rains, it may be taken that the method has rendered this nullah safe from mid-October to the end of April, *i.e.*, for 28 weeks.

Observations were made to see how far the effluent from the packing could be left without treatment before the breeding of malaria-carrying Anophelines commenced. This point is still uncertain. Breeding of both *A. fluviatilis* and *A. culicifacies* has been found on one occasion even in the section where the black sludge was deposited, although we have failed to find larvæ in places where water has been exposed by cattle trampling down the packing. It is thus not safe to trust that the effluent will remain free from larvæ for any great distance below the packing, and the idea that, in places where bush is scanty or needs transport from a considerable distance, it might be possible to control breeding by packing only in alternate sections, has had to be abandoned.

To obviate any danger from breeding in newly packed lengths it was decided, until the faunal changes were better known, to blow paris green mixture into the packing for the first fourteen days at the usual five-day intervals (*i.e.*, 3 rounds).

The second experiment was made at Chatikona Summit Station, 1,350 ft., eleven miles north of Theruvali. Here we packed, in December, a smaller ravine, with about six-foot banks, in similar scrub jungle. This ravine carries much less water than the North Nullah at Theruvali. The plant mostly used in this case was *Diospyros ebenum* (natural order Ebenaceæ). This plant is unfortunately not generally available, as it is a commercial forest product, providing the 'beedi' leaves that are used as wrappers for a popular Indian cigarette. With this plant no Anopheline breeding at all was noticed, but a very large brood of *Eristalis* occurred shortly after packing. The Culicines found are shown in Table II.

TABLE II.

Breeding in nullah 'N', Chatikona Summit, under herbage packing.

Species.	4-1-36.	24-1-36.	24-3-36.	12-4-36.	May.
C. fatigans	+	..	+	+	Washed out by severe thunder storm.
C. edwardsi	..	+	..	+	
C. gelidus	..	..	+	..	
C. fuscocephalus	..	..	+	+	
L. fuscana	..	+	+	+	
F. luzonensis	..	..	+	+	

At this station herbage packing has also proved effective in dealing with dead loops in the main river that runs through the protection area. These, except in times of flood, carry a minimal flow, but there is often a good deal of marginal seepage, so that a heavy expenditure of oil is required to control them.

The third experiment was a partial failure, and in consequence afforded very valuable information. It was carried out at Ambadola, 1,250 ft., two stations northward of Chatikona Summit. Here, within the control area, is a rice field in the forest, surrounded partly by high banks, in which arises so much seepage that paris green is liable to be carried away from the most dangerous spots in the field. Some years back, to cut off as much of the seepage water as possible, a bank foot drain was cut around the field. This has gradually cut itself down to hard soil at a depth of from 12 ins. to 5 ft., in

PLATE VII

Fig

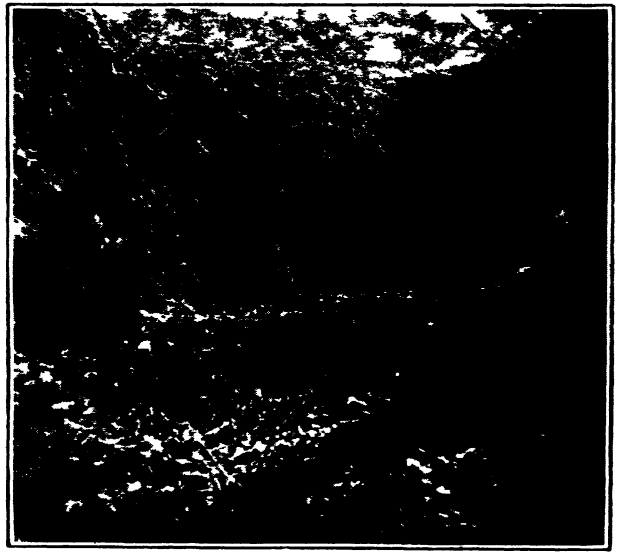

Fig 2.

Fig

Fig 1 -North Nullah, Theruvali, showing fence holding the packing and canalised open length beyond it

Fig 2 -North Nullah, Theruvali, herbage packed

Fig 3 -Ambadola Lifting the packing in paddy field drain to search for Anopheline larvæ.

which water runs swiftly*. The actual species of mosquitoes that would breed in this drain are not known, as it has all along been under weekly oiling, but the field on survey yielded *A. maculatus*, *A. funestus* subspp., *A. ramsayi*, *A. philippinensis* and *A. annularis*. This drain was packed, in December, with stems and leaves of a still unidentified bush†. The Inspector subsequently found Anopheline breeding (this was before it was realised that initial paris green dusting was necessary), and removed the packing and reverted to oiling. Shortly afterwards the writer made a visit, and ordered repacking. But Anopheline breeding was again found in the following month, January, the species being *A. fluviatilis* and *A. jeyporiensis*. On lifting the packing it was found that no rotting was occurring, and that it was merely functioning as a very rough subsoil drain. None the less it is hard to believe that, though an ovipositing female had penetrated the packing, soft newly emerged adults could have successfully worked their way out through it (Plate VII, fig. 3).

On thinking over the reason for this failure, the probable explanation was thought to be that whereas at Theruvali packing was mostly done in October-November, when the sap in the plants used was 'up' shortly after the end of the rains, by the cold weather in December the sap was 'down', and the leaves, with much less water content, would not decompose properly. This was confirmed by the results of packing the final stretch of the Theruvali Nullah, where also no rotting occurred, and in consequence, as Table I for April shows, Anophelines, though not of the original fauna of the nullah, were able to breed. On the other hand, *D. ebenum* will rot even in the dry weather. The packing at Chatikona was washed out late in March by a storm. It was replaced by fresh leaves, and these rotted nearly as well as the first packing.

These notes indicate that, to make a proper investigation into this method, the co-operation of both physiological and systematic botanists will be required.

The tables of mosquito-species findings given for Theruvali and Chatikona suggest that there is a definite 'species succession' in herbage packed water. Far more investigation must, of course, be carried out, but so far it is seen that *C. fatigans* is present throughout. *C. edwardsi* makes its appearance early in the process of rotting, as is confirmed by its reappearance in Table II after re-packing. *C. gelidus* is a later arrival, as is also *C. (L.) minutissimus*. The *Uranotaenia* has always failed to emerge, but it belongs to that section of the genus in which the frontal hairs of the larva are ensiformly flattened. *Lutzia fuscana*, as would be expected, appears when breeding is dense enough to suit its cannibalistic habits. The real puzzle is the almost constant presence of *Ficalbia luzonensis*. As far as is known, this genus is specialised for life among *Pistia stratiotes*, but nothing is on record about *luzonensis*, save my record (Senior White, 1925) of its having been collected in company with *A. maculatus* and *U. campestris* (a well-known pair of associates), in a rice field in the

* When this packing was first done, the Malaria Inspector complained that it so blocked up the flow of water in the narrow drain that this overflowed in the shallower lengths. This was obviated, when replacing, by placing the cut branches with their butts upstream. The current then forced the smaller leaf twigs against the stems, instead of spreading them out by its pressure. Thereafter no blocking occurred. In packing narrow drains or larger volumes of rapidly moving water, this point should be attended to, even at a slightly increased cost of work. It does not arise where there is plenty of water-way, or height of bank.

† Identified, whilst the MS. was passing through the press, as *Terminalia tomentosa* (natural order Combretaceæ) with an admixture of *Lagerstroemia parvi flora* (natural order Lythraceæ), and *Holarrhena antidysenterica* (natural order Apocynaceæ).

Ceylon sub-montane zone*. There has never been any *Pistia* in either of the nullahs now referred to. It is almost certainly a species of still water, and of presumably fairly pure water. Why it should be associated, and in numbers, with moving polluted water is extremely puzzling. *C. bitaeniorhynchus* finally appears when re-aëration is established, and with it the carrier Anophelines.

One fact, however, clearly emerges from these findings, *viz.*, that ovipositing mosquitoes can, in large numbers, penetrate the packing, which appears to act far less as a form of subsoil drainage than as a strictly biological control. This does not agree with Williamson's statements in his original description of the method. Perhaps there is more leaf and less stem in the wet zone Malayan scrub than in the Indian.

FINANCIAL ASPECT.

The saving effected by herbage packing over oiling is, of course, very great. On figures taken from the North Nullah at Theruvali, it is found that the entire length of this, within protection, is 5,200 ft. To treat this for 28 weeks, October 1934 to April 1935, cost 558 gallons of oil mixture and 280 days' labour, amounting in all to Rs. 358, which works out at As. 1 1 per foot run for the 28 weeks of the season. In the season 1935-36 not all the nullah has been herbage packed, the length in open country, where no scrub is available, having been left and oiled as usual. Thus the length packed only amounted to 3,785 ft. This cost 150 days in labour, plus an unknown, though very small, expenditure on paris green. The cost therefore came up to Rs. 61, equivalent to As. 0 26 per foot run for the season. The saving thus amounts to As. 0 84 per foot run per season, equivalent to 76 per cent of the cost of oiling. As this administration alone expends over 28,000 gallons of oil mixture annually, even if only a small percentage of the total water now under oil treatment can be dealt with by the new method, the financial import is very considerable.

Here also, for the first time, I think, appears a definite hope for anti-larval measures for the village, the apparent impossibility of which, on financial grounds, has so discouraged many workers. Had Wilson (1936) made his Indian tour a year later than he did, he might not have been constrained to state 'In actual fact everything we saw discouraged hopes of any future for malaria control by anti-mosquito measures in rural India'. For not only by Williamson's method can much of the ravine and irrigation channel breeding that so affects the health of many villages be eliminated, but perhaps by the use of the effluent, judiciously distributed, as a rich liquid manure in the actual rice fields, not only would the carrier-species breeding that now occurs in so many of them be eliminated, but the yield itself, by the certain increase it would show, would raise the general health, and so the resistance, of the villager. But, we must first be sure of what we are doing, and the preliminary desideratum is careful biological and chemical studies on water treated by this method. Such can only be carried out close to a laboratory; they are impossible in my own case, with my laboratory 700 miles from the field of the experiments. The need for the help of the botanist has been pointed out above. This preliminary note, therefore, is put out in the hopes that other workers will initiate experiments and publish their findings, so that the possibilities, and the limitations, of the discovery may be better understood. Enough, I think, has already

* I completely overlooked my own earlier record when I stated (Senior White, 1934) that nothing was known of the breeding habits of this species.

emerged to indicate its very great value in certain types of malaria protection work, and it will, generally it is hoped, and certainly within the writer's jurisdiction, be largely extended in the season 1936-37.

In conclusion I have to thank Dr. I. M. Puri of the Malaria Survey of India, for much help in Culicine identification, and would gratefully acknowledge the keen interest portrayed by Mr. Jogi Rao, B.Sc. *(Ag.)*, Mr. Narayana Rao, and Dr. R. Mondel, Malaria Inspectors of the Rayagada, Chatikona and Ambadola Sections of this railway's work, who have locally carried out the actual packing operations, and made the breeding observations, recorded in this paper, in addition to their routine duties of malaria control of the sections under their charge.

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MASS TREATMENT AND PROPHYLAXIS WITH ATEBRIN.

BY

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[25th May, 1936.]

THE present study was undertaken with the object of examining the effect of atebrin on both the asexual and sexual stages of the local strains of the three generally recognised plasmodia. The experiment was conducted in the Agricultural Farm, Bobbur, about two and a half miles from the Malaria Experimental Station at Hiriyur. This place was selected owing to its close identity with the malaria epidemiology of Hiriyur. As has been previously reported, there is a definite malaria transmission season in this area during the months from August through December; it also seemed probable that transmission occurred between February and June (Sweet, 1933; Sweet and Rao, 1931, 1933, 1934; Nursing, Rao and Sweet, 1934).

The resident population on the farm was 303, inclusive of staff. Except for the superior staff who were subject to transfers, the rest of the population was stationary.

EXPERIMENT.

Two courses of five days' treatment with atebrin only were administered to almost the entire population, the first course beginning on 23rd April, 1935, and the second on 12th November of the same year. Spleen and blood examinations of the entire group were made before and after each of these treatments by one of us (C. C.).

For these treatments adults received 0·1 gm. atebrin three times a day; children from two to ten years old were given 0·1 gm. twice a day, and children from 0 to two got 0·05 gm. twice a day. In every case the drug was administered by an inspector in the presence of the Health Officer and no one was given the drug to be taken later.

About a month after the close of the second course of treatment, commencing from 16th December, 1935, the same population group was given a further course of treatment with plasmoquine simplex for five days.

Unfortunately spleen and blood examinations immediately before and after this course of treatment were not made. The dosages of plasmoquine were for :

Adults .. .. .. 0 01 gm. twice a day.
Children (2 to 10 years) .. 0 01 gm. once a day.
Do. (0 to 2 years) .. 0·005 gm. once a day.

From the first of January to the end of November 1935, a weekly prophylactic dose of atebrin was given, the dosages being as follows :

Adults .. .. .. 0·2 gm. on one day a week (single administration).
Children (2 to 10 years) .. 0·1 gm. on one day a week.
Do. (0 to 2 years) .. 0 05 gm. on one day a week.

Spleen and blood examinations were done twice during this period, first in July and again in November 1935, at the close of the experiment.

The first two courses of treatment with atebrin were completed by 232 out of the total population of 303 and the course of plasmoquine treatment was completed by 271. The percentage of the population taking the prophylactic course varied from 91 1 to 62 0 per cent, but only 170 persons completed the entire programme. This report concerns only the findings for these 170 persons.

TOXIC EFFECTS.

Throughout the experiment no serious untoward effects were noticed beyond the pigmentation due to the atebrin used. This pigmentation gradually disappeared after the second treatment course and was not noticed during the prophylactic administration. The adults swallowed the drug without any complaints, but a slight difficulty was experienced in the case of children. The drug was rolled in small balls made of cooked ragi flour and no further difficulty was experienced.

In one case severe abdominal pain was complained of and twelve cases experienced mild intermittent abdominal pain lasting for a few hours during the last two days of the atebrin treatment course. Nausea and headache were complained of by ten persons.

SPLEEN AND PARASITE FINDINGS.

The observed spleen and parasite rates of the 170 persons who completed the whole programme are given in Table I. For purposes of comparison the spleen and parasite rates for the same periods of the Bobbur village, situated within a mile of the Farm and under no control measures of any kind are given in Table II.

TABLE I.

Spleen and parasite rates before and after the blanket treatments and during prophylactic course.

	BEFORE TREATMENT.		AFTER TREATMENT.	
	Spleen rate.	Parasite rate.	Spleen rate.	Parasite rate.
April 1934 ..	41·5	17·6	41·5	1·2
November 1934	25·6	7·1	25·6	1·2
July 1935 ..	..	..	20·9	1·7
November 1935	..	..	10·7	0·6

TABLE II.

Spleen and parasite rates of Bobbur village (comparison area).

	Spleen rate.	Parasite rate.
April 1934 ..	50·0	30·0
October 1934 ..	41·5	21·9
July 1935 ..	45·0	30·0
October 1935 ..	40·0	18·0

Tables III and IV give the percentage distribution of parasites and gametocytes respectively, of each species, before and after each course of treatment. Table V gives the percentage age distribution of the entire farm population as well as of the experimental group under discussion.

TABLE III.

Percentage distribution of parasites by species before and after treatments and during prophylaxis.

Treatment.		Number ex	Number infected.	Percentage	*P. vivax.* Number.	*P. vivax.* Percentage infected.	*P. falciparum.* Number.	*P. falciparum.* Percentage infected.	*P. malariae.* Number.	*P. malariae.* Percentage infected.
Atebrin 1st course.	Before	170	30	17·6	19	63·3	3	10·0	8	26·7
	After	170	2	1·2	..	..	2*	100·0	..	..
Atebrin 2nd course.	Before	170	12	7·1	5	41·7	4	33·3	3	25·0
	After	170	2	1·2	..	..	2*	100·0	..	..
Prophylactic course.	July 1935	170	3	1·7	..	..	2*	66·6	1	33·3
	Nov. 1935	170	1	0·6	..	..	1*	100·0	..	..

* Gametocytes only.

Before beginning any treatment the group of 170 persons had a spleen rate of 41·5 per cent and a parasite rate of 17·6 per cent, but at the end of the first course of five days' treatment with atebrin, although the spleen rate remained unchanged, the parasite rate had come down to 1·2 per cent, the difference of 16·4 ± 2 1 being statistically significant. Examinations at the commencement of the second course of atebrin treatment showed that the spleen rate had dropped to 25 6 per cent, whereas the parasite rate had risen from 1·2 to 7·1 per cent, both the reduction in the spleen rate and the rise in the parasite rate being significant. It would seem that the administration of atebrin had an immediate effect on the parasites, the effect of the reduced parasite rate being reflected by a reduction in the spleen rate six months later. That the parasite rate rose from 1·2 to 7·1 per cent during the interval between

TABLE IV.

Percentage distribution of gametocytes by species before and after treatments and during prophylaxis.

Treatment.		Number examined.	Number infected.	Percentage infected.	P. vivax.		P. falciparum.		P. malariae.	
					Number.	Percentage infected.	Number.	Percentage infected.	Number.	Percentage infected.
Atebrin 1st course.	Before	170	10	5·8	6	60·0	3	30·0	1	10·0
	After	170	2	1·2	..	..	2	100·0	..	..
Atebrin 2nd course.	Before	170	5	2·9	..	..	4	80·0	1	20·0
	After	170	2	1·2	..	..	2	100·0	..	..
During prophylaxis.	July 1935	170	2	1·2	..	..	2	100·0	..	..
	Nov. 1935	170	1	0·6	..	..	1	100·0	..	..

TABLE V.

Age distribution of the farm population and the experimental group.

Age group.	FARM POPULATION. TOTAL 303.		EXPERIMENTAL GROUP. TOTAL 170.	
	Number.	Percentage.	Number.	Percentage.
0 to 2 years ..	23	7·6	7	4·1
0 to 10 years ..	90	29·7	51	30·0
10 years and over	190	62·7	112	65·9

the two courses of atebrin treatment showed not only that a certain amount of transmission was going on during the period, but also that some of the apparently cured persons had suffered from relapses. In such endemic areas it is not possible to separate relapses from new infections.

The second course of atebrin treatment, while again showing no immediate effect on the spleen rate, brought down the parasite rate from 7·1 to 1·2 per cent. This reduction of 5·9 ± 4·2, while statistically significant, was not as great as that following the first course, but it is probably easier to reduce a fairly high parasite rate by treatment than it is to bring down the lower ones.

At the examination made in July 1935, subsequent to two courses of atebrin treatment, one course of plasmoquine treatment, and approximately six months of prophylactic atebrin, the spleen rate showed a reduction from 25·6 to 20·9 per cent, the difference of 4·7 ± 3·1 not being significant; there was also a slight, but non-significant, increase in the parasite rate from 1·2 to 1·7 per cent.

The last examination, just before closing the prophylactic dosing, established a spleen rate of 10·7 per cent and a parasite rate of 0·6 per cent. The drop in the spleen rate from 20·9 to 10 7 per cent was significant, the difference being 10·2 ± 2 6; the drop in the parasite rate from 1 7 to 0·6 per cent, while not statistically significant, because of the small rates involved, was undoubtedly of clinical importance.

During this same period the spleen and parasite rates of the comparison village, Bobbur, showed no significant variations. This points to the reduction in the rates in the experimental village as being directly due to the effect of the drugs administered.

Tables III and IV give the percentage distribution of the asexual and sexual forms of the three species of parasites before and after each course of atebrin treatment and during the period of prophylaxis. From Table III it is observed that the effect of atebrin on the asexual phase of the three parasites was the same during both courses, that is, while this drug completely cleared the peripheral circulation of the asexual phases of all three species, its effectiveness against the gametocytes was restricted to those of *P. vivax* and *P. malariae*. From Table IV it is clear that *P. falciparum* crescents are not so effectively controlled by atebrin, as at none of the four examinations were all persons of this group completely free (*Cf.* Komp and Clark, 1936). As against three people who showed crescents at the commencement of the first course of treatment, four showed crescents at the commencement of the second course, and only one at the end of the experiment.

During the whole experiment, 17,000 tabloids of atebrin and 1,500 tabloids of plasmoquine simplex were used for treating 170 people of all ages, at a cost of Rs. 1,472. The details of cost of each course of treatment are given in Table VI.

TABLE VI.

Statement of cost for the different courses of treatment.

	Quantity used.	Cost.*
Atebrin mass treatment (two courses of five days).	4,500	Rs. 369
Plasmoquine mass treatment ..	1,500	„ 78
Atebrin prophylaxis	12,500	„ 1,025
TOTAL ..	..	Rs. 1,472

*The cost of atebrin has since been reduced by 26·8 per cent.

The *per capita* cost of this plan of atebrin control of malaria works out at Rs. 11-13 per head per year. In calculating the cost, besides the cost of the drugs used, the cost of an assistant sanitary inspector at Rs. 30 per month is included. The maximum cost per head per year for malaria control of small population units in Mysore by paris green is estimated at Rs. 2 to Rs. 6, as computed from actual field experiments (Sweet and Rao, 1934).

SUMMARY.

1. Two courses at six months' intervals of atebrin blanket treatment were given for five days to a stable population of 170 people under control. These courses were followed by a five-day plasmoquine treatment, followed by prophylactic dosing with atebrin in the following doses :—

Adults	..	.. 0·2 gm. once a week.
Children	(2 to 10 years)	.. 0·1 gm. once a week.
Do.	(0 to 2 years)	.. 0·05 gm. once a week.

2. No untoward toxic effects were noticed during the experiment, though the majority of those treated were actually labourers carrying on their routine duties.

3. The parasite rate was significantly reduced at the close of each blanket treatment with atebrin.

4. The effect on the spleen rate was delayed but significant.

5. The prophylactic course of treatment, successfully kept down the spleen and parasite rates at the new reduced level.

6. A five-day course of atebrin treatment cleared the peripheral circulation of the asexual phases of all three species of malaria parasite.

7. Atebrin is effective against the gametocytes of *P. vivax* and *P. malariae*, but *P. falciparum* crescents are only partially removed.

8. The cost of atebrin treatment and prophylaxis works out at Rs. 11-13 per head per year as against an estimated *per capita* cost of Rs. 2 to Rs. 6 for malaria control by paris green.

In conclusion our thanks are due to Doctor W. C. Sweet for suggestions, to Mr. E. R. Sundararajan for his help in working out statistical values, and to the Director of Health for his kind permission to publish this paper.

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PHARMACOLOGICAL ACTION OF PLASMOQUINE.

BY

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Few drugs of recent years have attracted so much attention in tropical medicine as has plasmoquine, a synthetic quinoline product put on the market by Bayer. It was prepared by Schulemann and his colleagues in 1924, was first used by Muhlens in patients suffering from natural malaria in 1926 and by the end of that year was available for general clinical use. By the end of 1928, Brahmachari (1928) reviewed the available literature and referred to 145 publications on plasmoquine. By the end of the first half of 1930, Manifold (1931) observed that the number of publications dealing with plasmoquine was at least 325; which meant almost a couple of publications every week. Literature on plasmoquine is now extensive and the number of publications run in several hundreds. It is remarkable, however, that experimental studies on the pharmacological action of plasmoquine are remarkably few and a complete account of the action of the drug is still lacking.

It is not proposed to give the physical and chemical characters of the drug here. They have been referred to by several observers before [Schulemann, Schoenhoeffer and Wingler (1932); Green (1934); Brahmachari (1928)].

For all the experiments given below plasmoquine was used in the form of 1 per cent solution, supplied by the manufacturers in 3 c.c. ampoules

TOXICITY.

The toxicity was studied in dogs, cats, rabbits, guinea-pigs, leeches, protozoa and bacteria. The results obtained in the case of dogs, cats and rabbits were in general agreement with those obtained by Le Heux and Wijngaarden (1929) for these animals, but the drug was found to be a little more toxic than reported by these authors.

GUINEA-PIGS.

The toxicity was studied in guinea-pigs by oral administration of plasmoquine. The animals were starved for 24 hours before the administration of drug through a small gum elastic catheter introduced into the stomach. It was found that the dose which would kill 50 per cent of the animals was in the neighbourhood of 20 mg. per kg.

LEECHES.

Hirudo medicinalis were used for toxicity tests. The leeches were immersed in different concentrations of plasmoquine in 0·6 per cent saline and the time required to paralyse them was noted. The individual variation in the toxicity of the drug on leeches is considerable, the small leeches being more susceptible than the large ones. The following table shows the results obtained with the small variety :—

TABLE I.

The toxicity of plasmoquine on small leeches (Hirudo medicinalis).

	Concentration.					
	1 in 1,000	1 in 5,000	1 in 25,000	1 in 50,000	1 in 100,000	1 in 200,000
Time in minutes required to paralyse the leech.	10	25	40	150	Active after 24 hours.	Active after 24 hours.

Control active after 24 hours.

PROTOZOA.

Paramecia caudatum were used to note the effect of plasmoquine on protozoa. The paramecia were suspended in different concentrations of plasmoquine solutions and were observed under the low power of the microscope. The results are summarised in the following table :—

TABLE II.

Effect of plasmoquine on Paramecia caudatum.

Time in minutes.	Concentrations of plasmoquine.				Control.
	1 in 10,000	1 in 25,000	1 in 50,000	1 in 100,000	
5 minutes	—	+	+	+	+
10 "	—	—	+	+	+
15 "	—	—	+	+	+
20 "	—	—	+	+	+
25 "	—	—	—	+	+
60 "	—	—	—	+	+

— = Dead. + = Active.

It will thus be seen that a concentration of 1 in 50,000 of plasmoquine killed the protozoa in 25 minutes. This shows that the drug is not very toxic to the undifferentiated protoplasm.

BACTERIA.

The action of the drug was investigated on *B. coli* and *B. pestis*. To a series of test tubes containing an acid broth culture medium, different quantities of plasmoquine were added so as to give a concentration of plasmoquine

varying from 1 in 1,000 to 1 in 1,000,000. The tubes were inoculated with a pure culture of *B. coli* or *B. pestis* and incubated at 37°C., for 48 hours. The following table shows the results obtained :—

TABLE III.

Effect of plasmoquine on B. pestis.

Control.	Concentrations of plasmoquine.						
	1 in 1,000	1 in 5,000	1 in 10,000	1 in 50,000	1 in 100,000	1 in 500,000	1 in 1,000,000
+	−	±	+	+	+	+	+

+ = Growth. ± = Slight growth. — = No growth.

It will be seen that a concentration as high as 1 in 1,000 only can inhibit the growth of *B. pestis*. Similar results were obtained in the case of *B. coli*. Plasmoquine therefore does not appear to have any marked action on the growth of bacteria.

TEMPERATURE.

Sinton and Bird (1928) referred to the clinical findings of several workers on the effect of plasmoquine on temperature and recorded their own observations which were in general agreement with those of other observers. They found that the average duration of fever amongst plasmoquine-treated cases of malaria was 0 8 day, while in cases treated with plasmoquine co., it was only 0·3 day. Their records of malarial cases treated with different cinchona alkaloids showed that the average duration of fever for cinchona-treated cases was 0·31 day. They therefore arrived at the conclusion that plasmoquine alone has not so marked an action in reducing temperature in malaria as the cinchona alkaloids.

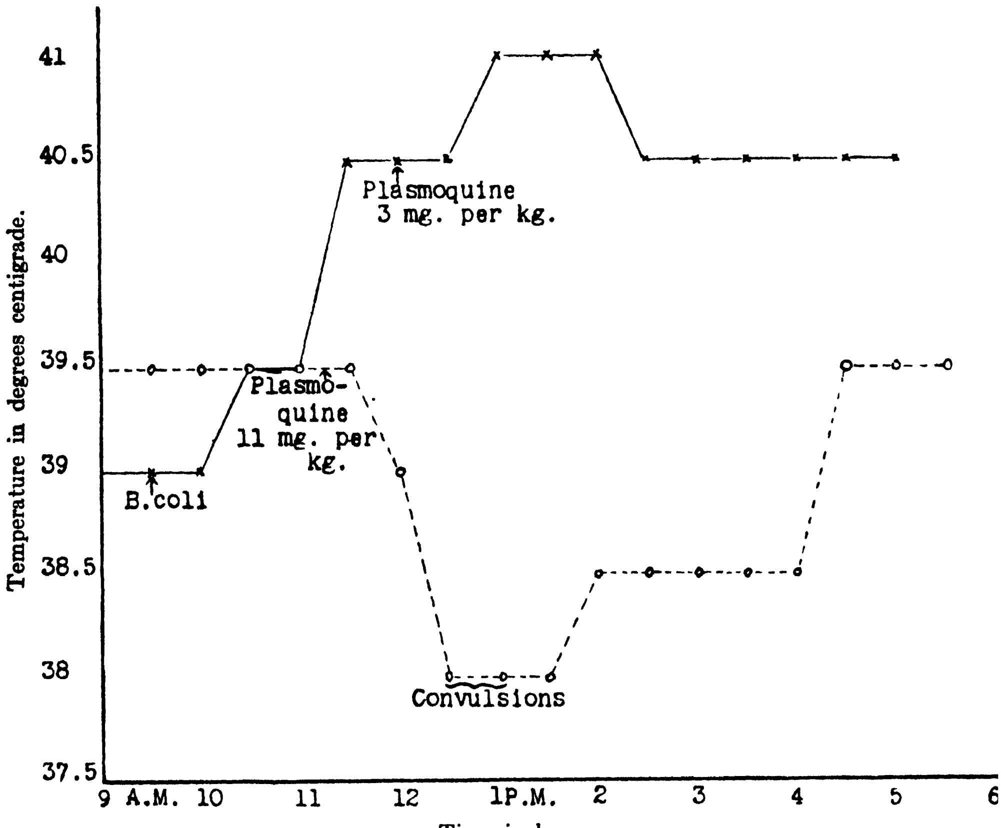
Apart from their specific action in malarial fevers the cinchona alkaloids possess a definite antipyretic action of their own. It has not been possible to get any experimental evidence in the literature to show that plasmoquine possesses a similar antipyretic action. Experiments were therefore made to see the action of plasmoquine on temperature. Kiliani's method (1910) was followed for the purpose. A four days' old broth culture of *B. coli communis* was killed by heating at 65°C., for 1 hour. 3·5 to 4 c.c. of this was injected hypodermically in rabbits weighing about 2 kg. Such an injection gave a rise of about 1·5°C. to 2°C., in the rectal temperature, which persisted for several hours. Plasmoquine was injected as soon as the temperature attained the high level. The drug was given in therapeutic and toxic doses, hypodermically. The following graph (Graph I) shows the nature of results obtained.

It will be seen from the graph that doses of plasmoquine of the order of 3 mg. per kg. have no antipyretic action. On the other hand, there is a slight increase in the temperature after such administration of plasmoquine. Toxic doses (10 mg. per kg.), however, lower the normal as well as fever temperatures considerably. One of the animals whose temperature chart is shown in the following graph was given 11 mg. per kg. plasmoquine hypodermically. In about

an hour and a quarter it showed tonic and clonic convulsions with slow respiration and an irregular heart action. The convulsions lasted for a period of about 45 minutes and were not very severe. The normal temperature of the rabbit was reduced by one and a half degrees. The temperature remained at a low level for about $4\frac{1}{2}$ hours and came to normal after that period and remained so afterwards. Similar results were obtained in rabbits with *B. coli* fever.

Some experiments were also made to see the antipyretic action of plasmoquine in combination with quinine. It was found that the degree of fall in

GRAPH I.



Continuous line shows temperature of a rabbit with *B. coli* fever. Note plasmoquine (3 mg. per kg.) produces little change except a small rise in temperature.

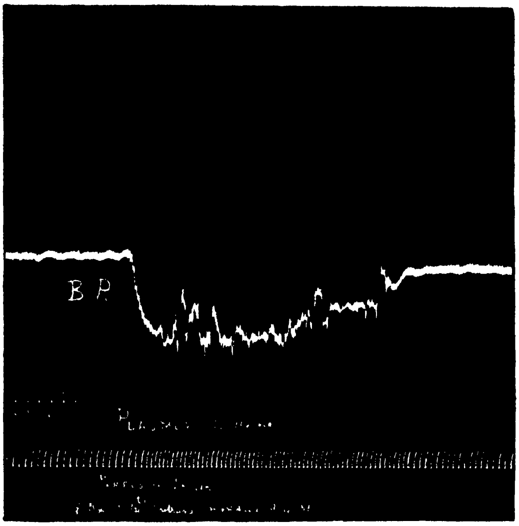
Broken line shows temperature of a normal rabbit. Note plasmoquine (11 mg. per kg.) produces a marked fall in the temperature.

the temperature of rabbits with *B. coli* fever was the same after plasmoquine in combination with quinine as with quinine alone. The combination, however, worked in a shorter time. It appears, therefore, that plasmoquine has no marked antipyretic action when given in therapeutic doses but is synergistic to quinine when given along with it.

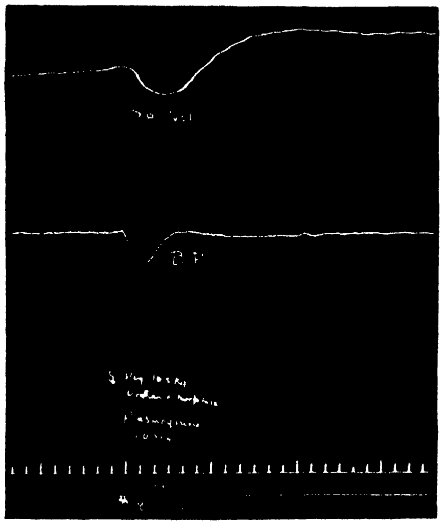
CIRCULATORY SYSTEM.

The action of plasmoquine on the circulatory system has been studied by some workers previously. Eichholtz (1927) injected plasmoquine in cats and rabbits intravenously and found that doses of about 2 to 3 mg. per kg., produced irregularity of the heart, and that the refractory period of the heart was increased. Adrenaline and quinine influenced this action favourably. More recently, De Langen and Storm (1935) made a careful study of the action of plasmoquine using monkeys for their experiments. They found that a dose of 0·4 mg. per kg. of body weight given intravenously produced a fall of blood pressure amounting to 50 mm. of Hg. A dose of about 1 mg. per kg. produced a fall accompanied by an irregularity of the heart. Section of vagi and atropinisation of the animal did not modify the action of the drug. They therefore concluded that the drug acted mainly peripherally.

Perfusing the monkey's heart by the Langendorff method the same authors found that after a concentration of 1 in 20,000 of plasmoquine the heart was stopped and could not be revived by perfusing with fresh Tyrode's solution. In perfusion experiments also very small concentrations of plasmoquine produced an irregularity of the heart. They further found some evidence to



A



B

Fig. 1.

Fig. 1, A.—♂ Dog, 7 kg., urethane-morphine anæsthesia. Tracings from above downwards:—B.P. = Carotid blood pressure; T. = Time 10 seconds interval; Perfusion inflow = Perfusion inflow of the hind limb; base line.

Plasmoquine (2 mg. per kg.) given intravenously at the mark in the base line. Note the fall in blood pressure with cardiac irregularity and increase in the rate of perfusion of the hind limb.

Fig. 1, B.—♂ Dog, 10·5 kg., urethane-morphine anæsthesia. Tracings from above downwards:—

Spl. Vol. = Spleen volume; B. P. = Carotid blood pressure; T. = Time 10 seconds interval; base line.

Plasmoquine (about 1 mg. per kg.) at the mark. Note the rise in spleen volume after a preliminary fall and a transitory fall in blood pressure.

show that the vasomotor centre in the medulla was depressed by administration of plasmoquine. The present series of experiments were made on cats and dogs. The animals were anæsthetised with urethane (1·8 gm. per kg.) or chloralose (0·1 gm. per kg.). In the case of dogs a preliminary dose of morphine (6 mg. per kg.) was given before the urethane injection. The blood pressure was recorded by the usual methods with a mercury manometer. For myocardiographs, the chest was opened under artificial respiration and the auricle and ventricle hooked up by small clips and connected to recording levers by fine threads.

Intravenous injections of small doses of plasmoquine (about 1 mg. per kg.) produced a transient fall in blood pressure with a rapid recovery (Fig. 1, B). This action was probably due to depression of the heart as well as dilatation of splanchnic blood vessels for the spleen volume was increased after a preliminary small decrease, the latter evidently being due to the general fall in blood

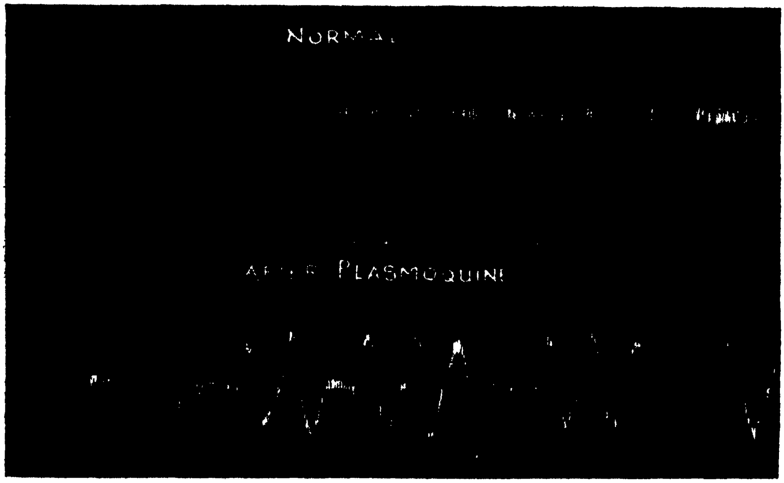


Fig. 2

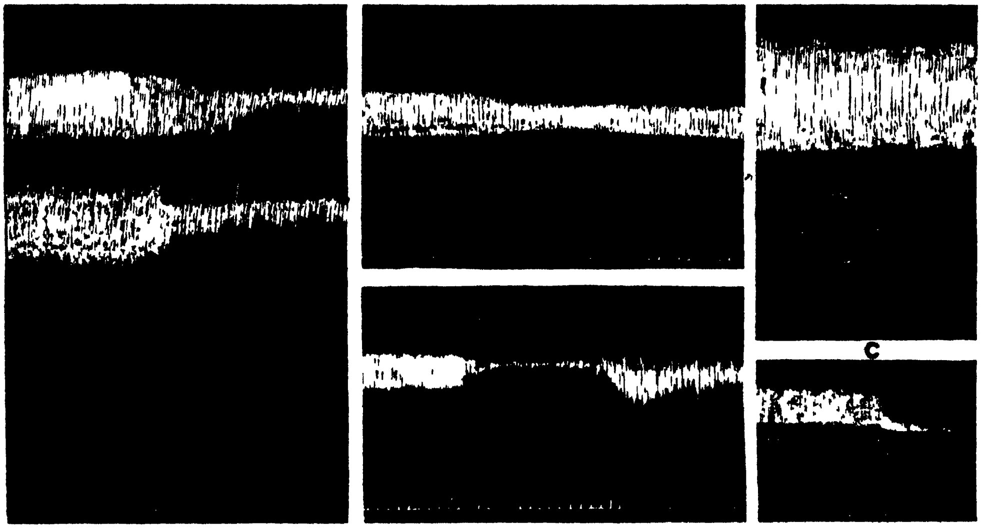
Electro-cardiograph of a dog's heart whose blood pressure is shown in Fig. 1, A.

Upper tracing, normal; lower, after plasmoquine.

pressure. Larger doses of the drug (about 2 mg. per kg.) produced a considerable fall in the blood pressure accompanied by an irregularity of the heart (Fig. 1, A). The nature of the irregularity is illustrated in the accompanying electro-cardiographic tracing (Fig. 2). It will be seen from the electrocardiograph that the normal action of the pace-maker was completely upset and most of the ventricular contractions were abnormal.

Figure 3, A, shows the irregularity of the heart produced in a cat after intravenous administration of a fairly large dose (2 mg. per kg.) of plasmoquine. The irregularity in this case lasted for about four minutes and the heart became normal after that period.

These effects on blood pressure and the heart were not affected by vagal section or atropinisation of the animals showing that the parasympathetic system was not concerned in the effects produced.



A B D

Fig. 3.

Fig. 3, A.—♀ Cat, 3·5 kg., urethane anæsthesia. Tracings from above downwards:—AUR. = Auricular contractions; VEN. = Ventricular contractions; T. = Time 10 seconds interval.

7·0 mg. of plasmoquine (2 mg. per kg.) given at the mark intravenously. Note the depression and irregularity of both the auricle and the ventricle.

Fig. 3, B.—Perfused rabbit's heart. Upper figure shows the effect of 1 in 200,000 and the lower of 1 in 100,000, plasmoquine. T. = Time 10 seconds interval.

Fig. 3, C.—♀ Rabbit, 2·5 kg., urethane anæsthesia; artificial respiration; lung volume and time at 30 seconds interval

Plasmoquine 2 mg. (0·8 mg. per kg.) injected intravenously at the arrow mark. Note slight constriction of the bronchioles.

Fig. 3, D.—Isolated rabbit's gut in Tyrode's solution.

Note that 1 in 300,000 plasmoquine completely paralysed the gut. T. = Time 10 seconds.

As has been stated above, De Langen and Storm found that the vasomotor centre was depressed by plasmoquine. The action of the drug on the vasomotor centre was studied by the following method :—

The hind leg of the anæsthetised dog was perfused with oxygenated Locke's solution at a constant pressure through a cannula tied into the femoral artery. The colateral circulation was cut off as far as possible by ligatures applied to different vessels. When the effluent from the femoral vein was clear, an intravenous injection of plasmoquine was given through the jugular vein. The drug in such experiments can influence the rate of perfusion of the limb through the vasomotor centre only. The inflow or the outflow or both were measured and the increase or decrease noted. Fig. 1, A, shows the results obtained in

one such experiment. The right leg of a dog under morphine-urethane anæsthesia was perfused with oxygenated Locke's solution from a mercury bulb fitted with a 'Mariotte stopper'. The rate of inflow was measured by counting the air bubbles entering through the Mariotte tube. An intravenous injection of plasmoquine (2 mg. per kg) was given at the mark in the base line. The tracing just above the base line shows the rate of perfusion inflow. It will be seen that the rate is markedly increased showing a dilatation of vessels which evidently must be due to depression of the vasomotor centre. A simultaneous tracing of the blood pressure record shows the fall in blood pressure and irregularity of the heart referred to already. It will thus be seen that depression of the heart is not solely responsible for the fall of blood pressure which is produced by an intravenous injection of plasmoquine.

Perfusion of rabbit's heart with Locke's solution by the Langendorff method showed a depression of the heart with low concentrations like 1 in 200,000; with higher concentrations like 1 in 100,000, a depression accompanied by a marked irregularity of the heart was produced. These effects are illustrated in Fig. 3, B, the upper tracing showing the action of a low concentration and the lower that of a higher one.

ACTION ON BLOOD.

Clinical use of plasmoquine in the treatment of malaria has brought into prominence its action on blood. One of the important toxic symptoms observed after the administration of plasmoquine is cyanosis due, as has been shown by several workers, to the formation of methæmoglobin. The susceptibility of animals varies a good deal in this respect as was first pointed out by Le Heux and Wijngaarden (1929). These authors found that *in vitro* experiments the blood of horses, cats, sheep and pigs, showed methæmoglobin formation in concentrations of 1 in 10,000 of plasmoquine, while that of rabbits and mice did not show methæmoglobin. If, however, the blood was hæmolysed the methæmoglobin formation was as rapid in rabbits as in cats. They also observed that the cat's blood was not hæmolysed by a concentration of 1 in 5,000 of plasmoquine. A high concentration of 1 in 1,000 produced slight hæmolysis after 3 hours, while a concentration of 1 in 200 was necessary to hæmolyse the red blood cells in 10 minutes.

Fischer and Rheindorf (1928) found in cases of malaria a gradual increase in the hæmoglobin percentage and erythrocyte counts after administration of plasmoquine. This effect appears to be due more to the action of the drug on malarial parasites than to its action on the blood directly. Fischer and Weise (1927) made the important experimental observation that if the number of erythrocytes suspended in a test tube containing a fixed concentration of plasmoquine is lessened, the methæmoglobin formation is increased.

Hypodermic administration of small doses (1 mg. per kg.) of plasmoquine did not show any appreciable change in the percentage of hæmoglobin or the erythrocyte counts in guinea-pigs.

The hæmolytic action of the drug was studied in cat's and dog's blood and the results were in agreement with those of Le Heux and Wijngaarden (1929). The action of the drug leading to the formation of methæmoglobin was studied in cats and dogs and the results were identical with those of Le Heux and Wijngaarden. The lowest effective concentration of plasmoquine that led to a definite formation of methæmoglobin *in vitro* experiment was found to be

1 in 10,000. Presence of plasma did not seem to affect this action, for the results were identical with whole blood and washed red blood cells. In all these experiments presence of methæmoglobin was detected by the spectrographic method.

The fragility of the red blood cells was studied in human blood as well as the blood of cats and dogs. The human blood was exposed to the action of 1 in 50,000 of plasmoquine and it was found that this concentration did not affect the fragility, hæmolysis occurring at 0·45 per cent saline as did the control.

Similarly, intravenous injections of large doses of plasmoquine into animals did not produce any change in the fragility of the red blood cells of the animals. A sample of blood was drawn from the femoral vein of cats under ether anæsthesia. The animals were then given a fairly large dose (5 mg. per kg.) in divided doses intravenously. The blood was withdrawn again after about 30 minutes and the two samples tested for the fragility of red blood cells, by suspending them in different concentrations of saline solutions. The following table shows the results obtained in one such experiment :—

TABLE IV.

Showing the fragility of cat's red blood cells before and after administration of plasmoquine.

	Concentrations of saline in per cent.								
	0·8	0·75	0·7	0·65	0·6	0·55	0·5	0·45	0·4
Control ..	—	—	—	—	—	—	+	++	+++
After plasmoquine.	—	—	—	—	—	—	+	++	+++

— = No hæmolysis. + = Hæmolysis.

ACTION ON RESPIRATION.

The results obtained in cats, dogs and rabbits were in general agreement with those obtained by De Langen and Storm (*loc. cit.*) in the monkeys. Plasmoquine produced a depression of respiration by affecting both the rate and depth of respiration. The depressant effect was often preceded by an initial stimulation. Fig. 4 shows the effect of a large dose of plasmoquine on the respiratory movements of a cat which were recorded through a cannula in the trachea. The initial stimulation is not seen, but the depression is quite evident and the effect lasted long after the return of the blood pressure to the normal.

The action on the bronchioles is illustrated in Fig. 3, C. The lungs of a rabbit were ventilated by artificial respiration and the lung volume recorded by passing a perforated brass tube through the pleural cavity. Plasmoquine was injected intravenously at the arrow mark. It will be seen that there is evidence of a slight broncho-constriction, but the effect is not very marked.

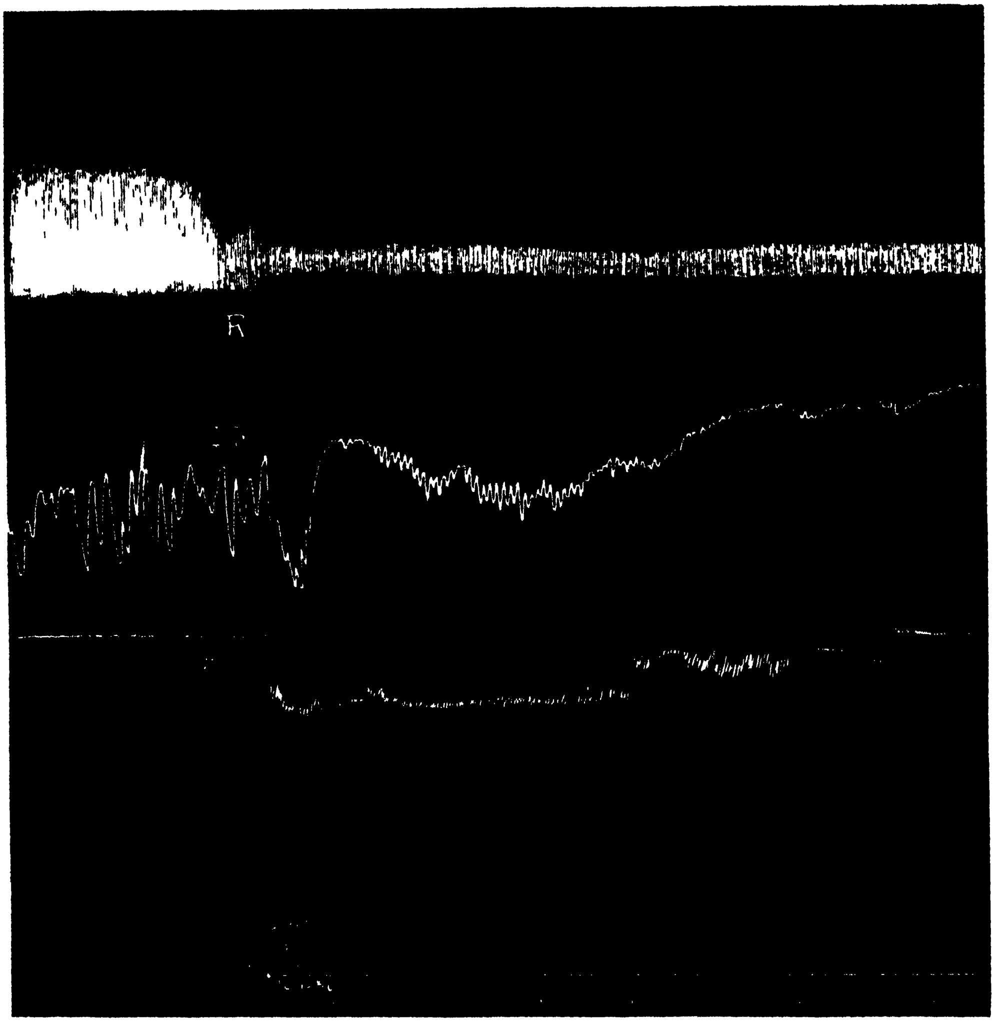


Fig. 4.

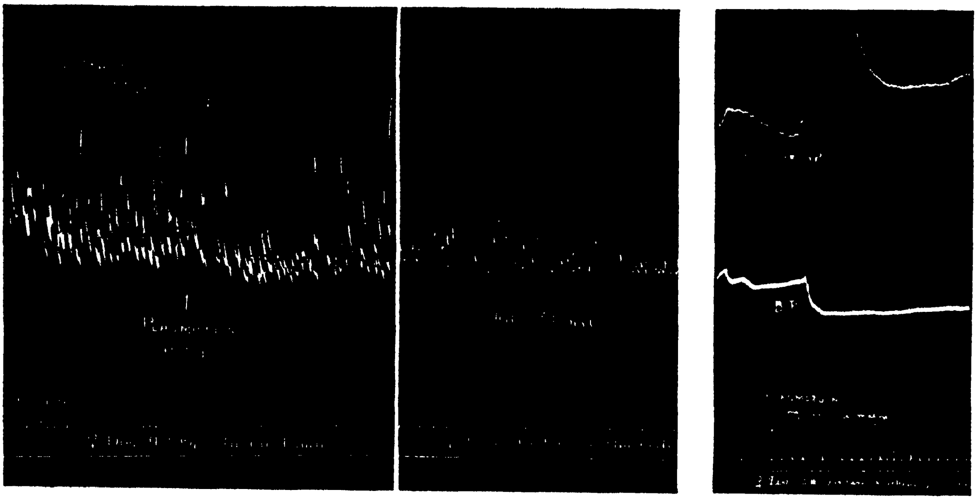
♂ Cat, 4·1 kg., urethane anæsthesia. Tracings from above downwards:—R. = Respiration; I. M. = Intestinal movements, contraction — ↓; B. P. = Carotid blood pressure; base line; T. = Time 10 seconds interval.

7·0 mg. of plasmoquine (about 1·7 mg. per kg.) injected intravenously at the mark in the base line. Note the depression of respiration; relaxation of the tone of the intestines and inhibition of automatic movements, and the fall in blood pressure. Note also that the B. P. returns to normal after about 11 or 12 minutes but the depressant effect on R. and I. M. persists.

ACTION ON DIGESTION.

Movements of the stomach were studied in dogs with a gastric fistula. The animals were operated several days before the experiment and the wound allowed to heal completely. Contractions of the stomach were recorded by

inserting a balloon through the opening of the fistula, filling it with water and connecting it to a Marey's Tambour. The drug was administered hypodermically and an injection was given to the animal without disturbing it, by using a sharp needle. Fig. 5, A, illustrates the action of plasmoquine on the stomach



A B

Fig. 5.

Fig. 5, A.—Stomach movements from a dog with gastric fistula. No anæsthesia. Left side shows the normal movements. Plasmoquine 40 mg. (about 4·5 mg. per kg.) injected hypodermically at the arrow mark. Tracing to the right shows the movements, 30 minutes after the injection Note the inhibition of movements. T. = Time 10 seconds interval.

Fig. 5, B — ♀ Dog, 10 kg, urethane-morphine anæsthesia. Tracings from above downwards:— Spl. Vol. = Spleen volume: B. P. = Carotid blood pressure; T. = Time 10 seconds interval.

Plasmoquine 0·1 mg. (0·01 mg. per kg.) injected into the cisterna magna at the mark. Note the rise in the spleen volume and a fall in the blood pressure.

movements. It will be seen from the figure that plasmoquine (about 4·5 mg. per kg.) inhibited the movements after about 30 minutes; this action persisted for several minutes afterwards.

The contractions of the gut are similarly inhibited and the tone relaxed by intravenous administration of plasmoquine. Fig. 4 shows the effect of intravenous plasmoquine on the movements of the small intestine. The blood pressure in this experiment came to normal in about 11 minutes, but the effect on the gut lasted for more than 35 minutes.

Isolated intestines of cats, dogs and rabbits show an inhibition of automatic contractions and a relaxation of tone of the intestinal muscle. The rabbit's intestine is particularly susceptible to the action of the drug and dilutions as high as 1 in 300,000 to 1 in 500,000 show a definite action. Fig. 3, D, shows the action of 1 in 300,000 concentration of plasmoquine on the rabbit's gut. Even such high dilutions produced a complete paralysis of the gut and although movements reappeared and the tone of the muscle improved after several

washings with fresh Tyrode's solution, neither the amplitude of contractions nor the original tone was regained. The important action of the drug, however, seemed to be on the liver. Details of these experiments form the subject of a separate communication. It may be mentioned here, however, that administration of toxic doses of plasmoquine, oral or parenteral, produced quite consistently a fatty degeneration of the liver in guinea-pigs. If the animal survived a toxic dose for more than 3 days, damage to the liver was consistently produced and fatty degeneration was invariably found if the animal died of plasmoquine-poisoning. In some experiments non-fatal doses were given by mouth and the animal killed after 3 or 4 days by a blow on the head. In such experiments also varying degrees of fatty degeneration of the liver were noted.

NERVOUS SYSTEM.

In discussing the circulatory system it has been shown that the vasomotor centre is depressed by the drug given intravenously. The direct action of plasmoquine on the vasomotor centre was studied by introducing small quantities of the drug into the cerebrospinal fluid. Fig. 5, B, shows the effect of such an injection on the blood pressure and the spleen volume of a dog. A very small dose (0·01 mg. per kg.) introduced into the cerebrospinal fluid of the cisterna magna through the atlanto-occipital joint produced a fall in the blood pressure accompanied by a marked rise in the spleen volume. The drug evidently acted on the vasomotor centre directly and produced a depression.

The action of plasmoquine on the respiratory centre similarly is one of depression and very small doses were required to paralyse the respiratory centre by introducing the drug into the cerebrospinal fluid of the cisterna magna.

In rabbits administration of toxic doses which would kill the animal in a few hours produce convulsions. These might be due to the inadequate nutrition of the brain owing to the fall in blood pressure and irregular heart action. In guinea-pigs the oral administration of toxic doses produces signs of general depression of the central nervous system. The animal lies on its side with slow respirations and goes into a lethargic condition. It appears therefore that the action of plasmoquine on the central nervous system is one of general depression.

REPRODUCTIVE SYSTEM.

The action of plasmoquine on the reproductive system will be dealt with separately in another communication. The results obtained so far were in general agreement with those of Chopra and his co-workers (1933). Low concentrations of plasmoquine such as 1 in 300,000 produced an increase in the tone of the isolated uteri of cats, guinea-pigs and rabbits, while higher concentrations produced the opposite effect. The intact uteri of cats, dogs and rabbits showed a slight contraction of their muscles after intravenous injections of the drug. The effect on the uteri of experimental animals, pregnant and non-pregnant, was less marked as compared with that of quinine.

DISCUSSION.

Experiments on the bacteria and protozoa indicate that plasmoquine is not a protoplasmic poison. Its action on the malarial parasites therefore appears to be more specific. Unfortunately, this special affinity for the parasite is accompanied by some side actions which just prevent the drug from gaining

the most coveted reputation of an ideal chemotherapeutic agent. Most of the experiments referred to in this paper have been made in animals with toxic doses; the results cannot directly be applied to human beings in their entirety. Toxic symptoms produced by administration of plasmoquine have, however, been reported by several workers and the modern tendency to reduce the dose is to be welcomed.

Experiments on temperature show that plasmoquine has no antipyretic action of its own but that a combination of quinine and plasmoquine works quicker as an antipyretic than quinine alone. The drug does not seem to increase the fragility of the red blood cells and does not hæmolyse the red blood cells except in concentrations which are never likely to occur in clinical practice. The most important action on blood, however, is that of formation of methæmoglobin, which leads to cyanosis. Experiments referring to the circulatory system show that when given by the intravenous route the drug is likely to precipitate cardiac irregularities. Small doses, however, produce just a depression of the heart and a fall in blood pressure. Intravenous administration, however, is better avoided as far as possible. The liver seems to be the main point of attack and whenever death took place in guinea-pigs after three days of administration of toxic doses of plasmoquine that was the organ which was consistently damaged. Many of the toxic symptoms which are met with clinically possibly originate in the damage to the liver.

SUMMARY AND CONCLUSIONS.

(1) Tests on protozoa and bacteria show that plasmoquine is not very toxic to these. Toxicity tests were also made in cats, dogs, rabbits, guinea-pigs and leeches.

(2) Plasmoquine has no antipyretic action of its own. In combination with quinine, however, it produces a quicker action than quinine alone.

(3) Plasmoquine reduces the blood pressure by acting directly on the heart and also by its action on the vasomotor centre.

(4) It depresses the respiration and constricts the bronchioles to a slight degree.

(5) The movements of the gastro-intestinal tract are inhibited. Plasmoquine produces a fatty degeneration of the liver cells when given in toxic doses.

(6) There is evidence of general depression of the central nervous system and a moderate stimulant action on the uterus.

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THREE YEARS' (1933 TO 1935) MALARIA CONTROL WORK IN CALCUTTA.

BY

K. L. CHOWDHURY, M.B.,
Mosquito Control Officer, Calcutta Corporation.

[10th June, 1936.]

CONTENTS.

1. LIEUT.-COLONEL COVELL'S SURVEY.

IN December 1931, the Malaria Sub-committee of the Conference of Medical Research Workers discussed the situation as regards malaria in Calcutta and its vicinity and passed a resolution recommending an enquiry to be undertaken by an officer of the Malaria Survey of India. Acting on this recommendation, the Government of Bengal requested Lieut.-Colonel G. Covell, I.M.S., then Assistant Director, Malaria Survey of India, to undertake an enquiry which lasted from 26th January to 25th February, 1932.

In order to estimate the prevalence of malaria in the city, Lieut.-Colonel G. Covell examined a large number of children for enlargement of spleen, and the blood of some of these was examined for the presence of malaria parasites. Children attending municipal schools between 6 and 10 years of age were selected for examination. Altogether 8,945 children were examined for enlargement of spleen and the blood of 3,294 of these was examined for malaria

parasites, at least 100 blood slides being taken from school children of each ward.

Of these, 322 were found to have enlarged spleen (roughly 4 per cent of those examined) and out of these 167 were considered to have certainly acquired their infection from outside Calcutta. Of the remainder, in some cases it was impossible to obtain a reliable history, but it was considered that the majority of them were probably locally infected. The total number of blood films found to contain malaria parasites was 85 (2·6 per cent of those examined). After making the survey Lieut.-Colonel Covell concluded as follows, 'Taking all the available evidences into consideration, it is clear that although endemic malaria in Calcutta is very slight in amount, there is an appreciable amount of local transmission of the disease, originating chiefly from cases imported from outside, and that in some parts of the city there was an unusually large number of cases in 1931..........It appears probable that the incidence of malaria in Calcutta decreased from about the year 1925 to 1930, and that it is now (1932) on the upward grade'. He further observed 'If the breeding places are allowed to continue in their present condition, it is exceedingly probable that in the future the prevalence of locally acquired malaria in Calcutta will be increased, and will form a factor of definite economic importance in the life of the city'.

After enumerating the different species of anopheline mosquitoes found in Calcutta Lieut.-Colonel Covell remarked, 'The only one which is to be seriously considered as a malaria carrier in Central Calcutta is *A. stephensi,* though *A. varuna* may play some part in the transmission of the disease in the suburban areas'. As a remedy against this he recommended 'a vigorous campaign against the breeding places of *A. stephensi*'. He made further recommendations as follows, 'The nature of these breeding places, which are exclusively man-made, are well known. The measures required were laid down in detail by the writer in his report on malaria in Bombay, 1928, a copy of which is forwarded with the present note. It is strongly urged that the efforts of the anti-mosquito organisation recently sanctioned by the Corporation of Calcutta be directed in the first place against the breeding places of *A. stephensi*......' As regards *A. sundaicus* (*ludlowi*) he commented as follows :—'We must now consider the possibilities of *A. ludlowi* establishing itself in the most important areas which would affect Calcutta itself. There are (1) the swamp near Majerhat, and (2) the Salt Lake area. As regards Majerhat, extensive breeding of *A. ludlowi* in this locality would be of grave danger to the docks and to the shipping berthed there. The Majerhat swamp is gradually being filled up with silt from the bed of Tolly's Nullah, but it will take at least five years to complete the work. Fortunately, the salinity of the water in the swamp is considerably lower than the optimum concentration for the breeding of *A. ludlowi*, analysis of samples taken at various points during 1931 showing a salt percentage of from 0·006 to 0 025. Furthermore, adult specimens of *A. ludlowi* must have been conveyed to the Majerhat station in the trains from Falta in considerable numbers before their presence was detected in August 1931; yet no larvæ of this species were ever found in water collections near the station. For these reasons, I do not think that the breeding of *A. ludlowi* in the Majerhat swamp is likely, especially, if the breeding places at Falta are efficiently controlled'.

'As regards Salt Lake area, the position is rendered grave by the silting up of the river Bidyadhari, which has only occurred very recently. Until this

happened the lake was tidal, but now this is no longer so, and it is even found necessary at times to drain water off from it into the canal which runs along its northern border. The sewage outfall from Calcutta is discharged into the Bidyadhari, and the silting up of the river means that a certain amount of organic pollution will occur in the lake. This will be no deterrent to the breeding of *A. ludlowi* and may in fact be favourable to it, for as we have seen the species can tolerate a high degree of pollution, and some observers have even stated that it prefers breeding places which are thus contaminated. There is, however, one factor which is favourable, and that is that at any rate on the side of the lake nearest to Calcutta there are no small pools, and I understand that in the rainy season especially the whole lake consists of enormous sheets of water; whereas, *A. ludlowi* as a rule prefers small collections of water as breeding places. Nevertheless, the situation requires careful watching and the provision of an organisation prepared to apply rigid control measures should occasion arise'.

2. WORK DONE BY THE CALCUTTA CORPORATION.

In 1930 Dr. K. S. Ray, then Chairman of the Public Health Committee, formulated a scheme for the control of mosquitoes in Calcutta. The scheme came into operation in 1932. According to this scheme the city is divided into 42 units, each unit being under the charge of a sub-inspector who is either a qualified medical man or a passed sanitary inspector. Each sub-inspector is in charge of a certain area of the city and has a number of workers under him. He controls, supervises and directs their work. The work of the sub-inspectors is supervised by four inspectors, who are directly under the Mosquito Control Officer. The laboratory work is entrusted to an Entomologist. Since the separation of Garden Reach (Ward No. 26) in April 1935, the number of units has been reduced by four, with a corresponding reduction in the staff. Each sub-inspector has eight men under him on an average. The size of the unit is variable, depending upon the number of breeding places, the number of houses, etc. The biggest in size has an area of 1,241 acres with 4,614 occupied houses within its jurisdiction. Most of the unoccupied houses are locked up, and so it is almost impossible to enter into them; hence in calculating the work of a unit the number of occupied houses only is taken into consideration. The smallest area controlled by a unit consists of 147 acres with 3,723 occupied houses. The staff of each unit is required to perform the following duties :—

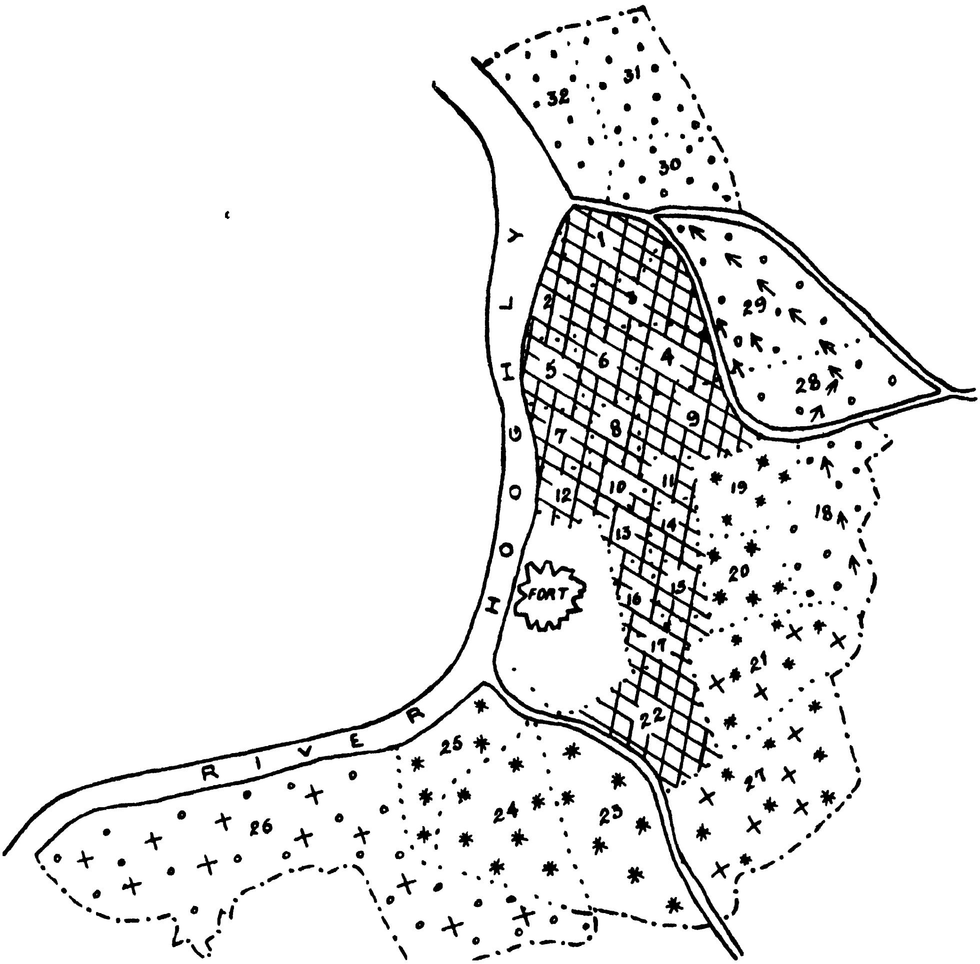
(*a*) to keep a record of all the permanent breeding places;

(*b*) to inspect all permanent collections of water at least once a week and to discover any temporary breeding place;

(*c*) to destroy all mosquito larvæ either by applying kerosene or paris-green or any other larvicidal measure; in some cases, *e.g.*, masonry cisterns, broken tins, pots, etc., the receptacle is only emptied;

(*d*) the sub-inspectors are required to sign house-inspection cards once a week: house-inspection cards (a copy of which is inserted at the end of the article) are distributed throughout the unit. These cards are kept by the occupier of the premises. The sub-inspector or his staff visits the house, inspects the breeding places, treats them and signs the card, putting the date on it, and describes the work done by him. This acts as a check on the work of the sub-inspector;

MAP OF CALCUTTA.



Showing distribution of malaria-carrying mosquitoes.

A. stephensi (intense amount) . . . . . .

A stephensi (moderate amount) . . . .

A. stephensi (very small amount) . . . .

A. sundaicus . . . .

A. varuna . . . .

(*e*) every sub-inspector is required to send his daily report to the Mosquito Control Officer. The daily report contains the addresses of all the premises visited by the staff, indicating the nature of the breeding places and the treatment accorded. A superior officer selects from the daily report some house at random and verifies the work done in that place. If any discrepancy is noted the sub-inspector is taken to task. A blank daily report form inserted at the end of the article shows the various items of information contained in that report. This method has proved extremely useful in checking the work of the sub-inspectors.

The staff of each unit is expected to visit all the premises within its jurisdiction once in every seven days. Sunday is reserved for major operations like tank-cleaning, jungle-clearing, etc. It will be seen that in the daily report there is a column showing the premises where treatment has been refused; whenever the employees of the Corporation are refused admission the Mosquito Control Officer serves a notice on the occupier of the premises, demanding right of inspection under Schedule XVIII (1) of the Calcutta Municipal Act of 1923. In cases where mosquitoes are found breeding the Mosquito Control Officer may, if he thinks proper, require the occupier to prevent this under Schedule XVIII (7) of the Act. The appropriate sections of the Act are printed on the back of the notice issued.

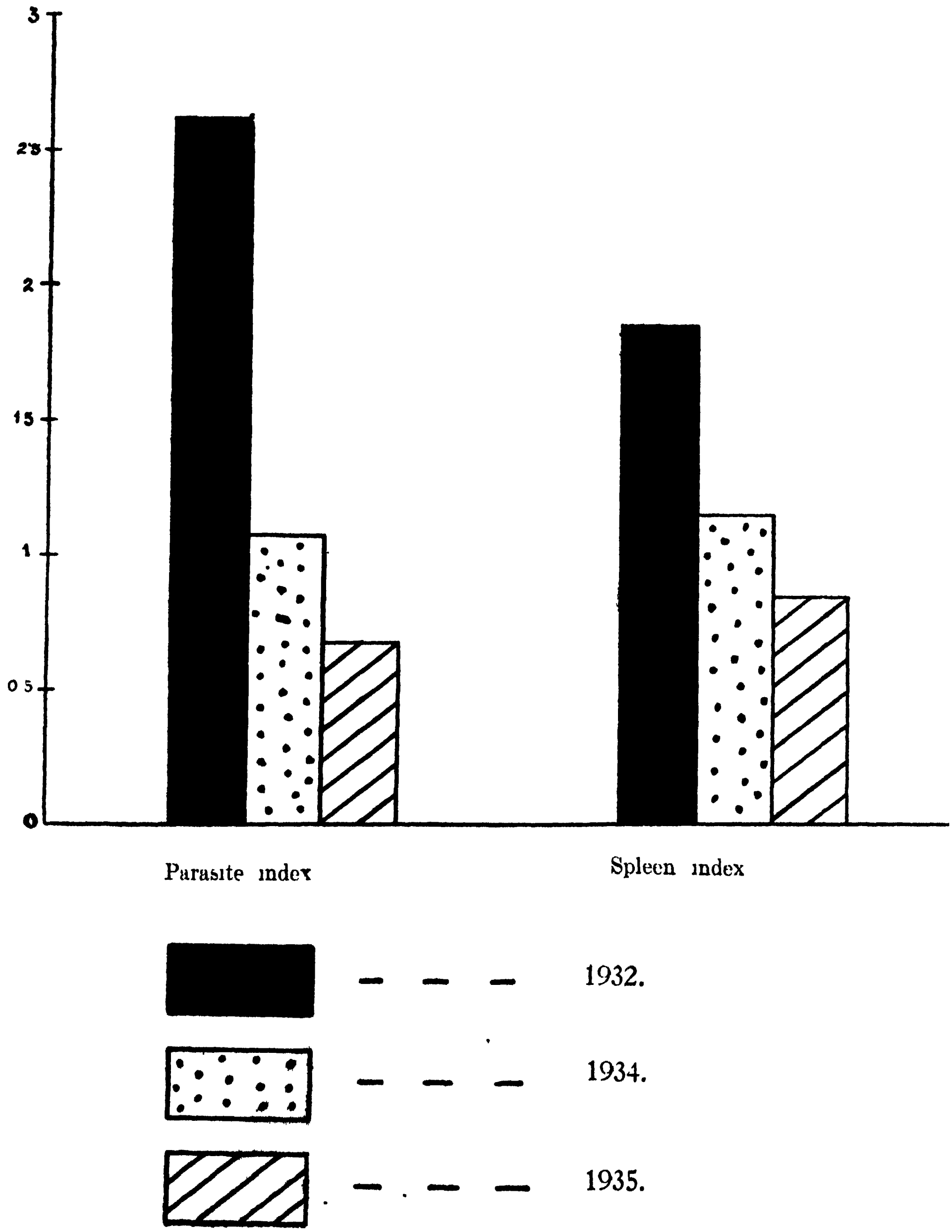
The object of the Mosquito Control Department is 'to prevent mosquito-borne diseases and to stop mosquito nuisance in the city'. This department in accordance with the objects laid down, tries to stop mosquito nuisance, as far as practicable, with the limited resources at its command, but special stress is always laid on the prevention of mosquito-borne diseases, especially malaria.

The three species of anophelines incriminated as the malaria carriers are: *A. stephensi*, *A. varuna* and *A. sundaicus*. Of these, *A. stephensi* is by far the most important. The unfiltered-water cisterns which are used for storing water for flushing privies provide the principal breeding places for this species. The silt-laden water is not inimical to the growth of larvæ, as was pointed out by Iyengar (1920). As the pressure of filtered water in Calcutta is very low, many people collect the water in masonry cisterns on the ground level and then pump it up by means of a hand or electric pump into iron cisterns on the roof. These filtered-water cisterns breed *A. stephensi* larvæ equally well. The next in order of importance are the masonry cisterns which are absolutely necessary for storing water in Calcutta, as the supply of water is intermittent. It has been shown (Ganguli, 1935) that in Calcutta iron cisterns and masonry cisterns are responsible for about 84 per cent of the breeding of *A. stephensi*.

Under the circumstances existing in Calcutta the best method of dealing with the *A. stephensi* problem is to prohibit these man-made breeding places, or if this be impossible, to render these cisterns mosquito-proof. So long as a continuous supply of water at high pressure is not available, cisterns remain a necessity. At present the Corporation supplies 63,900,000 gallons of filtered water and 53,900,000 gallons of unfiltered water per diem; yet complaints about low pressure and scarcity of water, especially in summer, are common. Even when Moore's scheme—which is now partly in operation—is completed, the prospect of having a continuous supply of water at high pressure is very remote, especially in view of the rapid expansion of the city. Hence the only possible

permanent measure is to render the cisterns mosquito-proof. On the recommendation of the Mosquito Control Advisory Committee and the Public Health

GRAPH.



Standing Committee, the Corporation at their meeting on 15th January, 1936, approved the by-laws as set forth below :—

(1) Every cistern and reserve tank of water shall be mosquito-proof and with that end in view shall comply with the following conditions :—

(*a*) The lid shall be well fitted and of the pattern approved by the Executive Engineer, Water Works, and shall be kept closed by strong bolts and nuts.

(*b*) The warning pipe or overflow pipe attached to the cistern or reserve tank shall be protected by a metal cap of standard pattern approved by the Executive Engineer, Water Works, and not by wire gauze.

(*c*) The punch-hole made by the Corporation Water Works Department shall be either utilised for connecting pipes or properly closed.

(*d*) Water gauges necessitating an aperture in the roof or side of a cistern shall be mosquito-proof.

(2) No new water connections should be given to any premises until the storage cisterns installed therein have been certified mosquito-proof by the Executive Engineer, Water Works, in accordance with the by-laws.

(3) Every cistern and reserve tank shall be numbered by the Corporation in a conspicuous place to facilitate inspection.

(4) Every cistern and reserve tank shall be kept in good repair or changed.

(5) (*i*) If any cistern or reserve tank be found on examination by the Mosquito Control Officer to be non-mosquito-proof or otherwise not in compliance with any of the aforesaid conditions he may, by written notice, require the owner or occupier of the premises (*a*) to replace the same or (*b*) to make such alterations therein as may be specified in the notice.

(*ii*) If any notice issued under the aforesaid by-law is not complied with within seven days from the date of service thereof, the Corporation may forthwith carry out the work and the costs thereof shall be payable by the person to whom the notice was issued.

(*a*) These by-laws will be enforced only in case of replacement of old cisterns or reserve tanks by new ones and provision of new cisterns or tanks.

(*b*) If any licensed plumber is found to put in a new cistern or reserve tank, which does not conform to these by-laws, his license will be revoked.

As regards *A. sundaicus* it must be remembered that it is found breeding only in tanks, low-lying lands and canals on the eastern border of the city. Out of 450 tanks and ponds existing in the *sundaicus*-affected area of the city,

including wards 18, 28 and 29, *A. sundaicus* has actually been found breeding in about 100 cases, as shown in the following table :—

Locality.	Number of tanks existing.	Number breeding *A. sundaicus.*	Number under paris-green treatment.
Ward 18 (Pagladanga) ..	47	9	9
„ 28 (Nebugola)	157	30	30
„ 29 (Manicktolla, Bengal Chemical).	62	16	16
„ 29 (Bagmari)	181	45	45

Owing to the vigorous anti-larval measures adopted, the number of adult mosquitoes in catching stations is small. Weekly paris-greening is done over all tanks breeding *A. sundaicus.*

A. varuna larvæ are found in old tanks with a small amount of marginal vegetation in the southern and south-eastern quarters of the city (wards 20, 21, 26 and 27). Since the separation of Garden Reach in April 1935, which formerly constituted ward 26 of the Calcutta Corporation, and with the rapid urbanisation of wards 21 and 27 by the Calcutta Improvement Trust the problem of *A. varuna* is fast dwindling in importance so far as the city of Calcutta is concerned. At present, weekly paris-greening is done whenever any breeding place is detected.

During the year 1935 about one hundred and fifty maunds of paris-green mixture were used, the paris-green being employed in a dilution of 5 per cent in soft-stone powder. Mysto rotary blowers and Peerless dust-guns were used for applying the paris-green mixture. During the same year, 60,000 gallons of oil were used, the oil used being a mixture of crude oil and kerosene oil in the proportion of 1 to 2. Ordinary brass garden syringes were used for spraying oil, though Knapsack sprayers were utilised when necessary. For running water 'oil balls' (balls made of rags, jute, saw-dust, etc., soaked in oil) were often used with advantage. For the destruction of adult mosquitoes about 1,000 gallons of different kinds of insecticidal sprays were used.

In this connection it is useful to remember that the city covers an area of 31 square miles with a high level of sub-soil water. The water supply being intermittent with a daily output of 63,900,000 gallons of filtered and 53,900,000 gallons of unfiltered water, an enormous number of cisterns and receptacles are in use throughout the city, each of which is a potential breeding place for mosquitoes. As stated in the *Corporation Year Book* for 1936, the number of filtered-water connections is 56,418 and the number for unfiltered is 45,961. Each water connection means at least one, and in the majority of cases two or three, reservoirs for storage of water. Besides 334 miles of surface drains, there are numerous tanks, ponds, marshes, etc. These, however, are of lesser importance, at least so far as the breeding of *A. stephensi* is concerned.

3. EFFECT OF THREE YEARS' MOSQUITO CONTROL ON THE SPLEEN INDEX.

A glance at the table showing the results of the malaria survey in 1935 compared with those made in the three previous years will at once show that both the spleen and the parasite indices have gone down in Calcutta. In 1932

the splenic index was 1·73, in 1934, 1·17 and in 1935, 0·84 showing a reduction of 51 per cent, since 1932. Similarly, in 1932 the parasite index was 2·6, in 1934, 1·03, and in 1935, 0·64, showing a reduction of 75 per cent since 1932.

Municipal school children are examined for enlargement of the spleen and presence of malaria parasites in the blood every year. The examinations are conducted in November, which is the month of maximum malarial morbidity. During the Puja holidays in October a large number of people go to villages from Calcutta and bring malaria back with them. With a large number of *A. stephensi* abounding in the city these malaria-stricken patients form excellent foci for the spread of the disease. Also, during the Puja holidays a large number of villagers, many of whom are gametocyte carriers, visit Calcutta and help to spread the disease. For these reasons, November was selected for determining the spleen and parasite rates each year. Children between the ages of 2 to 10 years were examined, the majority being between 5 and 10 years old. Inquiries were made as regards the place and duration of residence of each child and as far as possible these factors were taken into consideration in determining the splenic index of the different wards, and of the city as a whole. For instance, many children attend the free primary schools of the Calcutta Corporation though they live in adjacent municipalities beyond the limits of the Calcutta Corporation. In these areas as might be expected, the malaria rate is decidedly higher. On an average about 100 children were examined from each ward. The examiners were mostly qualified medical men, and their work was supervised by the Entomologist and the Mosquito Control Officer.

4. SUMMARY.

(1) Lieut.-Colonel Covell undertook a malaria survey of the city of Calcutta in 1932 and recommended among other measures a vigorous campaign against *A. stephensi* by the anti-mosquito organisation of the Calcutta Corporation.

(2) The Mosquito Control Department of the Calcutta Corporation started a vigorous campaign against all mosquitoes laying special emphasis on the *A. stephensi* problem.

(3) In 1932 the spleen index was 1·73, in 1934, 1·17 and in 1935, 0·84, showing a reduction of 51 per cent since 1932. Similarly, in 1932 the parasite index was 2·6, in 1934, 1·03 and in 1935, 0·64, showing a reduction of 75 per cent since 1932.

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APPENDIX A.

Result of a malaria survey of Calcutta in 1935 and its comparison with malaria surveys in previous years.

Ward No.	Number of children examined.*	Number showing enlarged spleen.	Spleen index.	Number showing malaria parasite in blood.	Parasite index.	Survey of 1934.		Major Covell's survey in 1932.		Remarks.
						Spleen index.	Parasite index.	Spleen index.	Parasite index.	
1	100	1	1·0	...	...	1·4	...	2·2	...	Dots indicate *nil.*
2	90	1	1·1	1	1·1	2·0	...	3·0	...	
3	129	2	1·5	1	0·8	1·1	0·3	1·8	...	
4	91	1	1·1	1	1·1	0·8	1·6	2·7	1·0	
5	106	1	0·9	1	0·9	...	..	2·0	3·0	
6	116	2	1·7	2	1·7	...	...	1·6	...	
7	72	1	1·4	...	...	...	0·9	1·0	2·0	
8	100	1	1·0	1	1·0	1·0	1·0	1·0	5·0	
9	99	1	1·0	...	...	2·7	0·9	0·7	3·0	
10	104	...	...	1	0·9	...	0·9	1·5	4·0	
11	101	1	1·0	. .	...	1·5	0·8	1·0	2·0	
13	90	...	...	...	...	2·7	...	2·2	7·4	
14	100	2	2·0	1	1·0	1·8	1·8	3·3	4·0	
15	43	1	2·3	...	..	5·0	10·0	2·5	15·0	
18	119	1	0·9	1	0·9	2·5	2·5	2·0	2·0	
19	80	1	1·2	...	...	1·2	1·2	0·7	2·0	
20	106	...	...	..	...	1·2	...	1·4	2·0	
21	100	1	1·0	1	1·0	2·4	2·4	3·8	8·0	
22	101	...	...	...	...	0·5	1·1	1·5	1·0	
23	108	1	0·9	...	...	...	2·5	1·0	2·0	
24	134	1	0·7	1	0·7	1·6	...	3·0	...	
25	105	...	...	...	...	...	...	1·0	...	
27	231	2	0·8	3	1·3	1·2	2·4	...	7·0	
28	96	1	1·0	1	1·0	0·9	1·7	2·5	4·0	
29	97	1	1·0	...	...	1·9	...	1·8	1·0	
30	94	1	1·0	2	2·1	...	...	1·1	3·0	
31	111	...	...	...	...	...	1·2	2·0	2·0	
32	134	...	...	1	0·7	...	1·5	1·4	3·0	

*C. F. P. school-children aged 6 to 10 years were examined in November 1935.
C. F. P. = Corporation Free Primary.

Results of the last three years.

	1932	1934	1935	Remarks.
Total number of children examined.	8,945 for spleen 3,294 for malaria parasite.	3,004	2,957	
Percentage with enlarged spleen.	1·73	1·17	0·84	Reduced by 51·45 per cent since 1932.
Percentage with malaria parasite in blood.	2·60	1·03	0·64	Reduced by 75·39 per cent since 1932.

APPENDIX B.

CORPORATION OF CALCUTTA.

MOSQUITO CONTROL DEPARTMENT.

HOUSE INSPECTION CARD.

Resident.. No. ....

Address...

Date.	Iron Cisterns.	Masonry Cisterns.	Fire buckets.	T. C. W.*	Signature of M. S.-I.†

* Temporary collections of water. † Mosquito Sub-Inspector.

APPENDIX C.

CORPORATION OF CALCUTTA.

MOSQUITO CONTROL DEPARTMENT.

No. M. C. O.........

Dated the................193 .

FROM

THE MOSQUITO CONTROL OFFICER.

To

THE OWNER OR OCCUPIER,

Premises No................................

SIR,

(*a*) I beg to inform you that my staff was refused inspection of your premises on their last inspection day (date..................). My men are duly authorised by the Chief Executive Officer to inspect premises for sanitary purposes under Schedule XVIII, Rule 1, of the Calcutta Municipal Act of 1923.

I request you, therefore, to be good enough to allow my men to perform their duty.

(*b*) I beg to inform you that Anopheles and Culicine mosquitoes were found breeding on the last inspection day of my staff (date................) on your premises in :—

(1) Overhead iron cisterns :
 Unfiltered water.
 Filtered water.
(2) Masonry cisterns.
(3) Fire buckets.
(4) Flower tubs.
(5) Drains.
(6) Tanks, ponds.
(7) Low land, Borrow-pit.
(8) Odd receptacles.

Under Schedule XVIII, Rule 7, of the Calcutta Municipal Act, 1923, you are hereby requested to prevent the breeding of mosquitoes in your premises by taking the following action :—

I have the honour to be,
Sir,
Your most obedient servant,

Mosquito Control Officer.

THE CALCUTTA MUNICIPAL ACT, 1923.

SCHEDULE XVIII.

Rules for the Inspection and Regulation of Land and Buildings.

Rule 1 :—

(1) The Corporation may cause any building or other premises to be inspected for the purpose of ascertaining the sanitary condition thereof.

(2) If the Corporation have reason to believe that any building is used as a public lodging-house or is let out in rooms to twenty-five or more lodgers such inspection may be made at any time by day or by night:

Provided that no such inspection shall be made by night except by an officer specially authorised by the Health Officer in that behalf.

Rule 7 :—

(1) When—

(*a*) any well, pool, ditch, tank, pond, pit or marshy or undrained ground, or

(*b*) any cistern, reservoir or water-butt or any other receptacles or place where water is stored or accumulated, or

(*c*) any waste or stagnant water, whether within any private enclosure or not, appears to the Corporation to be or to be likely to become injurious to health or offensive to the neighbourhood or in any other respect a nuisance, they may, by written notice, require the owner or occupier of the land or building to which such well, pool, ditch, tank, pond, pit, ground, cistern, reservoir, water-butt, receptacle, place or water pertains,

to cleanse or to fill up the same with suitable materials or to drain off or remove water therefrom or to take such other order therewith as the Corporation may deem necessary.

(2) Where, in the opinion of the Health Officer, such well, pool, ditch, tank, pond, pit ground, cistern, reservoir, water-butt, receptacle, place or water is or is likely to become a breeding place for mosquitoes, he may enter upon the premises to which it pertains and take such steps as he thinks proper to cleanse the same.

(3) If the Corporation in exercise of the powers conferred by section 510, execute any work referred to in a notice issued under sub-rule (1), and if the person liable to pay the expenses of such work fails to pay the same, the Corporation may until such expenses are paid,—

(*i*) lease any part of the land used in connection with the said well, pool, ditch, tank, pond, pit, cistern, reservoir, water-butt, receptacle, place or water or any part of the said ground, as the case may be, or

(*ii*) retain possession of the same, or the site thereof, and utilise it for public purposes.

(4) If the said expenses be paid by an occupier of land, he may, in the absence of any agreement to the contrary, deduct the same from any rent due to the owner of the land.

APPENDIX D.

Daily Report of the Mosquito Brigade.

DATE

M. S. I. UNIT NO.

SARKARS (1) WARD

(2)

SECTION

INSPECTION.

Streets	Premises No	H I Cards signed

TREATMENT.

Breeding places		Inspected	Breeding	Treated	Cleaned.	Removed	Treatment refused	Notified	REMARKS
1. Iron cisterns*	U F W								
	F. W								
2. Masonry tanks ..	..								
3 Tubs and receptacles	..								
4. Unserviceable articles	..								
5. Gully pits† ..	..								
6. Drains ..	..								
7. Tanks ..	..								
8. Pools and others ..	..								
9 Wells ..	..								
10. Cess-pits ..	..								
Total No. of premises ..	..								

*U.F.W. = unfiltered water.
F.W. = filtered water.
† includes street-gullies and yard-gullies.

LARVICIDES USED.

Oil.	Paris-green mixture.	Phenyle.

DETECTION OF BREEDING PLACES.

Address.	Breeding in	Anophelines or culicines.	Owner or occupier.	Serial No. of samples sent.	Remarks.

Sub-Inspector. .. *Inspector.*

Records of the Malaria Survey of India, **6**, 3, *September*, 1936.

ABSTRACT.

A BRIEF PRELIMINARY REPORT OF THE MALARIA SURVEY OF HALTUGAON IN THE DISTRICT OF GOALPARA, ASSAM*.

BY

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SUB-ASSISTANT SURGEON G. S. DAS,

AND

SUB-ASSISTANT SURGEON S. C. ROY.

(MS. 11 pp. with one Sketch Map.)

[18th June, 1936.]

THE survey was undertaken with the object of instituting control measures against the mosquito nuisance and the prevalence of malaria at Haltugaon.

Haltugaon is a Forest Settlement situated in Goalpara District, Assam, about 18 miles from the foot of the Bhutan Hills. It covers 160 acres, and is bounded on the north by a small stream and a Sal forest. On the east and south it is bounded by the winding course of the Gaurang river and on the west by a permanent 'Dong'. The river is small in size and water flows in it throughout the year.

The population of the area surveyed which included villages within a radius of one mile around Haltugaon is 700 and consists of an indigenous and an immigrant element.

The meteorological data are approximate as they are not recorded at Haltugaon.

The climate is humid and the hottest month of the year is August. The rainy season begins in April and continues till October, the total annual precipitation being about 160 inches. The month of heaviest rainfall is June, while December is the driest month.

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* Copy of the original manuscript has been placed in the Library of the Malaria Survey of India, Kasauli. This is available on loan to workers who wish to consult the original. (*Editor*).

Records of births and deaths were not available. During the period 1931 to 15th November, 1935, four cases of blackwater fever (three deaths) and four cases of cerebral malaria (three deaths) were recorded.

The results of spleen and blood examinations among children and adults may be summarised in Table I.

TABLE I.

Results of spleen and blood examinations.

	Total number examined.	Spleen rate, per cent.	Parasite rate, per cent.
Children under 2 years	28	92·85	85·71
Children: 2 to 12 years	230	90·86	69·13
Adults	401	49·12	44·63

The author noted the interesting phenomenon of an enhanced spleen rate amongst the immigrant population of 64 46 per cent, as compared with a rate of 25·77 per cent among the indigenous element.

The gametocyte carrier rate in children and adults was almost the same, being 26·41 and 21 33 per cent respectively.

As regards the species of parasite, malignant tertian predominated both in children and adults, forming about 60 per cent of infections.

Adult catches of anophelines disclosed the presence of ten species (Table II). The figures in parentheses show the number of each species dissected. Larval collections showed seven additional species.

TABLE II.

Collections of anopheline mosquitoes.

Found as adults and larvæ.	Found as adults only.	Found as larvæ only.
A. vagus (218) ..	*A. fluviatilis* (2)	*A barbirostris.*
A. minimus (443) ..	....	*A. maculatus.*
A. hyrcanus (29) ..	....	*A umbrosus.*
A. annularis (16) ..	....	*A. culicifacies.*
A. philippinensis (27) ..	....	*A stephensi.*
A. subpictus (6) ..	....	*A leucosphyrus.*
A. kochi (2) ..	....	*A. aconitus.*
A. gigas	....	....
A. aitkeni	....	....

Results of dissection of adult mosquitoes show that *A. minimus* is the carrier in this locality. Out of a total of 443 dissections of this species, 3 were found with infected gut and 3 with sporozoite infection of the salivary gland, giving oöcyst and sporozoite rates of 0·67 per cent and a total infectivity rate of 1·35 per cent. This species was found to breed chiefly in the Gaurang river

throughout its course. 'The extensive grassy edge of the Gaurang with slow current affords ideal breeding places of *A. minimus*'. No infection was detected in the other species of mosquitoes.

In the Sketch Map showing the location of the breeding places and adult catches it is noticeable that no larvæ of *A. minimus* was found in swamps, 'Dong' or wells in this locality.

The number of malaria cases treated monthly at Haltugaon dispensary from 1930 to 15th November, 1935, is tabulated. It shows that the largest number of cases occurred yearly in May, that is, about one month after the onset of the rains.

The annual consumption of quinine and cinchona febrifuge is given.

The area is declared to be hyper-endemic, and the recommendations for dealing with malaria are detailed. These include the appointment of a special antimalaria officer and staff, mosquito-proofing of Government residential quarters and mass treatment with quinine and plasmoquine.

The annual cost of the treatment of the breeding places, which include the trimming of banks of the river, oiling and paris greening is computed at Rs. 6,660. This includes the salary of the antimalaria staff.

G. C.

Records of the Malaria Survey of India, 6, 3, September, 1936.

THE EFFECT OF VITAMIN DEFICIENCY ON ANTIBODY PRODUCTION AND RESISTANCE TO INFECTION.

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INTRODUCTION.

EVIDENCE is accumulating to show that an adequate and well balanced dietary has a marked influence on the resistance of an animal to various infections. The subject is still in its infancy, and it is difficult to foresee the extent of its development by future work. Theoretical considerations would suggest, *a priori*, that a well-nourished animal should possess greater resistance to infection than an under-nourished animal and that if antibody production be a function of the cell, any condition that impairs the cellular activity will also interfere with its capacity for antibody production.

It appears that in dealing with this subject of great practical importance, the investigators, in this field, have devoted considerable attention to the study of the influence of vitamin deficiency on bacterial rather than protozoal infections. While discussing and evaluating our experimental observations on the **influence of deficient diet on the incidence and relapse of malaria,* we shall make frequent references to the effect of nutrition on resistance to infection in bacterial diseases, on which comparatively more work has been done. It is proposed, therefore, to consider in this review the problem of the susceptibility of man and animal to bacterial infections, and to find out, from the available evidence, as to what extent the bacteriological, immunological and protozoological researches have shown that vitamin deficiency affects resistance to infection and antibody production.

AVITAMINOSIS.

A. EFFECT OF VITAMIN A DEFICIENCY.

Werkman (1923) carried out an extensive investigation on the immunological significance of vitamins. Rabbits and rats on vitamin A deficient

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* To be published in a later issue.—*Editor.*

diets showed lower hæmolytic titre in response to immunisation with rabbit red blood cells than the controls. Osborn (1932) noted that complement tended to be lower in such cases than in the blood of controls receiving cod-liver oil. Werkman (1923) further showed that vitamin A deficient rats and rabbits were more susceptible to inoculation with *B. anthrax* and *diplococcus* than the controls. This was confirmed by Lassen (1930) who showed that vitamin A deficient rats have a greatly reduced resistance to infection with *paratyphoid bacilli* and by Ackert *et al.* (1931) who found vitamin A deficient chickens infested with *Ascaridia lineata* have larger and more numerous worms than chickens on a complete diet.

Mori (1922), Goldblatt and Benischek (1927), and Mellanby and Green (1928, 1929) in their pathological studies on vitamin A deficient rats found that there was metaplasia of the normal columnar type of epithelium to the squamous keratinised type in parts of the respiratory, alimentary and genito-urinary tracts, the para-ocular glands and the eyes. Seifried (1930) working on chickens fed on vitamin A deficient diet found tissue changes in the respiratory tract in the form of an atrophy and degeneration of the lining epithelium of the mucous membranes as well as of the glands of the mucous membrane. He further observed that the protective mechanism inherent in the mucous membranes of the entire respiratory tract is seriously damaged, or even entirely destroyed by the degeneration of the ciliated cells at the surface and the lack of mucus secretion with bactericidal properties. Secondary infections were frequently found and nasal discharge and various kinds of inflammatory processes were common, including purulent ones, especially in the upper respiratory tract, communicating sinuses, eyes and trachea.

Seifried also found that, when fowls were placed on a diet lacking in vitamin A, lesions appeared in the upper alimentary tract which were confined largely to the mucous glands and their ducts. Histologically, it was shown that the original epithelium was replaced by a stratified squamous keratinising epithelium and that secondary infections were relatively common. The ducts of the glands were liable to be blocked leading to distension with secretions and necrotic materials. These lesions macroscopically resembled very closely certain stages of smallpox. He pointed out that these lesions produced by lack of vitamin A may enable bacteria and other viruses to enter the body.

These observations have been supported by Wolfe and Salter (1931) on albino rats. Hume and Smith (1928) reported many infections in rats on A-free diets. Sherman and Burtis (1928) added further evidence to support the anti-infective theory by experiments on two large groups of rats of which one group was placed on a border line A deficiency for the first four weeks of life before being depleted of vitamin for a month. This group showed 75 per cent of infections, whereas the control group on normal diet showed only 25 per cent. Their observations even suggest the possibility that vitamin A deficiency early in life may render the organism more susceptible to infectious diseases at a later age. This is in line with the experience of Bloch (1931) who found an abnormally high premature death-rate among individuals who suffered in childhood from eye disease of dietary origin.

The increased susceptibility of man to infections of the skin in vitamin A deficiency have been noticed by Mori (1904), Pillat (1929), Bloch (1931), Spence (1931) and Loewenthal (1933). Corroboration of these results can be seen in the high incidence of infective disorders found in the prisoners on diet

deficient in vitamin A at Kampala in Uganda by Mitchell (1933). In 1927, when xerophthalmia with keratomalacia was common amongst these prisoners, dysentery, diarrhœa, pneumonia, and bronchial affections were rife and the death rate abnormally high, *i.e.*, up to 200 per 1,000 per annum. By altering the diets, this high death rate was brought down to 14 per 1,000. The high incidence of bronchitis, pneumonia, tropical ulcers and phthisis among the Kikuyu tribe who live on a diet mainly of cereals as compared with the low incidence of these diseases among their neighbours, the Masai, who live on milk, meat, etc., as stated by Orr and Gilks (1931), probably has a similar or related nutritional explanation. The differences in distribution of infective disease found by these workers in the two tribes are most impressive.

Green, Pinder, Davis and Mellanby (1931) showed by making observation on 550 women, half of whom received a supply of preparation rich in vitamin A, that vitamin A therapy given before childbirth increased resistance of the genito-urinary tract to invasion by micro-organisms.

Laboratory experiments of Mellanby and Green (1928) showed that the mucosa of the parous uterus is more susceptible to infection when the diet is relatively deficient in vitamin A, during or after pregnancy, and are in keeping with their clinical results. Taken in conjunction with the clinical investigations, this nutritional aspect of preventing puerperal sepsis in women is undoubtedly one of great practical importance.

Zimmerman (1933) considers it probable, though the evidence is as yet incomplete, that lesions in the central nervous system may result from prolonged vitamin A deficiency.

It may, however, be questioned that since most of the studies were made on such anti-infective sources as cod-liver oil and butter fat, whether the effect was due to vitamin A or some other constituents, important among them being vitamin D. This may apply to most of the work on vitamins with the exception of that in which irradiated ergosterol was used. The recent success, however, in the isolation of vitamins and their precursors opened the way for much better controlled work on resistance.

Mellanby (1928) showed that vitamin A and not vitamin D protected the lungs from inflammatory changes in atelectasis. Following Euler's (1928) observations on the replacement of vitamin A by carotene for growth of rats, Green and Mellanby (1930) showed that carotene also prevented infection and the response in the intensity of infection was related to the amount of carotene administered; with 5γ there is very little, if any, protection against infection, while with 40γ protection is complete. It is probable that if these observations were repeated with the purer samples of carotene now available, protection against infective lesions would be produced by smaller doses than the above. Green and Mellanby (1930) taking advantage of this fact showed that a specimen of carotene (melting point 174°C.) had the property of conferring complete immunity on growing rats against the development of spontaneous infections. Also that animals fed on a diet free from vitamin A and carotene invariably developed septic foci and died, and when carotene was given with food the amount of protection conferred on the animals was generally proportional to the amount of carotene eaten. Green (1933) observed that in vitamin A deficient rabbits spontaneous infections occurred and that they were susceptible to intravenous injections of type I pneumococcus than the control animals.

Sutherland (1934) however has made the observation, surprising enough at first sight, that extra vitamins A and D, added to the diet of children of the lower working classes, did not have any appreciable effect even on the growth and resistance against infections. This anomaly, however, could be explained by the fact that the diet was grossly inadequate in various other respects, and that these other factors were left uncorrected.

McCollum (1936) while reviewing the literature on fat-soluble vitamins remarks that 'vitamin A is a factor in reducing somewhat the severity and duration of cold in young adults, although not a specific against colds, and not to be considered a cure for colds'.

From the available evidence it may be concluded that vitamin A is essential for the well-being of man and animal and that it is concerned with maintaining the integrity of the epithelial structures. It may thus increase the resistance of the organism to infection and possibly to other degenerative changes. In man, vitamin A deprivation has been associated with night blindness and with changes in the epithelium of the cornea and para-ocular glands, which ultimately lead to xerophthalmia. Mucous membranes are particularly affected and this may be a factor in the development of upper respiratory infections. In animals there is likewise the involvement of the genito-urinary tract, but to what extent this occurs in man has not yet been established.

B. EFFECT OF VITAMIN B DEFICIENCY.

McCarrison (1919) observed that hens fed on polished rice were far more readily infected with *Bacillus aertryke* than control birds, while Biondo (1922) and Setti (1922) reported that pigeons on diet lacking in vitamin B are no longer immune to infection with *Bacillus anthracis.*

McCarrison (1919) further reported that among the changes in severe vitamin B deficiency was the development of lesions in the gastro-intestinal tract, and Farmer and Redenbaugh (1925) observed that the gastric and pancreatic secretions were depressed with accompanying reduced enzymatic activity.

Bentley (1893) described 52 cases of beriberi, 28 of which appeared to have been the sequel of malaria or dysentery and allied conditions. These cases were observed in Java. If the diets in common use at that time were at all like those employed in the prisons as described by Vodermann (1907), then they were probably on the border line with respect to adequacy of vitamin B. Three cases of beriberi following relapsing fever were reported by Yacoub (1918), and in each instance there was prolonged feeding with condensed milk, a food containing liberal amounts of vitamin G, but relatively small quantities of the B factor. Walshe (1918) observed 40 cases of beriberi in Egypt, and of these, 19 per cent showed a previous history of malaria. Cannon (1929) makes the contention that 'the dry and the dysenteric forms of beriberi are really camouflaged forms of malaria'.

Findlay (1923) found that diets lacking in vitamin B produced in pigeons and rats definite changes in the hæmopoietic tissues, consisting of congestion and hæmorrhage in bone marrow followed in the more chronic cases by gelatinous degeneration. Pigeons fed on vitamin B deficient diet became susceptible to infection with *pneumococcus* organisms to which they are naturally immune, and also showed greater susceptibility to infection with *Bacillus coli* and *Bacillus enteritidis.*

The reduction of natural immunity has been found to be related to body temperature produced by diets deficient in vitamin B. This effect is only marked when the cloacal temperature falls to 40°C. or below. The lowering of body temperature may decrease the resistance by (*a*) facilitating the growth of the invading organisms, (*b*) reducing the leucocytic response to the infection and (*c*) reducing the bactericidal power of the leucocytic exudates.

Pfannstiel and Scharlan (1930) reported that yeast (vitamin B) and cod-liver oil accelerated healing in experimental *staphylococcus* infection of skin.

Cowgill (1935) considers that gastric ulcer is another disorder which can conceivably be related to vitamin B deficiency. In so far as the treatment of this condition usually involves a marked restriction of diet, the occurrence of at least a moderate shortage of this vitamin is by no means unlikely. Obviously the length of the period of dietary restriction would be an important determining factor. Dalldorf and Kellogg (1931) also observed in rats subsisting on carefully controlled diets that the incidence of gastric ulcer was greatly increased in vitamin B deficiency.

Observations of this nature merit serious consideration. The careful clinician should, therefore, give proper attention not merely to the treatment of the ulcer itself, but to the maintenance of a satisfactory nutritive state as well, and this will necessitate the administration of vitamin B together with other important nutritive factors.

C. EFFECT OF VITAMIN C DEFICIENCY.

Smith (1913) observed that epidemics of pneumonia due to the *pneumococcus* and *B. bronchiosepticus* infections in guinea-pigs were much more during winter when the diet was deficient in greens than in summer when the diet contained abundance of them. Moreover Findlay (1923) has shown that guinea-pigs fed on a diet deficient in vitamin C succumb to a smaller dose of infections with *streptococcus, staphylococcus* and *pneumococcus* than animals fed on a complete diet. He noted that the symptoms of toxæmia manifested themselves more rapidly in scorbutic than in control animals, either because the tissues, especially the heart, were more susceptible to the action of toxins formed by the action of bacteria, or because in these animals there was more toxin formed by the bacteria as a result of some rupture in the defence mechanism of the body.

In chronic scurvy such a degeneration is usually met with in the bone marrow. It, therefore, seems not improbable that the lesion in the bone marrow may at least be one of the factors in the reduction of resistance to bacterial infection exhibited by animals with chronic scurvy. Werkman (1923) has found increased susceptibility in scorbutic guinea-pigs to infections of anthrax and pneumonia. Coulaud (1924) reported tuberculosis in the guinea-pigs to be hastened by C deficiency. Mouriquand *et al.* (1924) however showed that lesions in C deficient guinea-pigs were no worse than in normals with infections of diphtheria and anthrax.

McConkey and Smith (1933) fed tuberculosis sputum to guinea-pigs suffering from hypovitaminosis C and to animals on a normal diet. Ulcerative intestinal tuberculosis developed in the deficient animals and not in the controls.

Evidence is accumulating to indicate the anti-infectious effects of ascorbic acid. King and Menten (1935) as well as Polony (1935) showed that the resistance of guinea-pigs against diphtheria toxin was increased by large doses of ascorbic acid given *per os* or by injection. The trend of recent experiment

thus confirms the impression that under certain circumstances deficiency of vitamin C may cause a marked diminution in resistance to certain types of infection (Harris, 1935).

D. EFFECT OF VITAMIN D DEFICIENCY.

When discussing the effects of vitamin A it was pointed out that results ascribed to vitamin A might equally have been due to its admixture with vitamin D. In the treatment of and resistance to tuberculosis, however, the action of vitamin D *per se* seems possible. Grant (1927 and 1930) who lowered the resistance of white rats by placing them on rachitic diet found that they were susceptible to subcutaneous injections with bovine tubercle bacilli. Eichholtz and Kreitmair (1928) observed a higher mortality among rachitic rats than among controls when a spontaneous paratyphoid epidemic occurred. They also reported that the rachitic rats were more susceptible to infection with *pneumococcus* type I than the controls. Green (1933) made an extensive study by producing experimental rickets in rabbits fed on McCollum's rachitic diet and found them to be less resistant to inoculation with *B. lepisepticum* and *pneumococcus* and showing a higher morbidity and mortality following intranasal *pneumococcus* type I, than the controls.

BLOOD STUDIES.

The foregoing considerations indicate that there is certainly an anti-infective quality in vitamin A, with some possibilities in regard to B, C and D. To find out the possible explanation of the effects of these vitamins investigators have turned their attention to the study of the blood elements.

Cramer, Drew and Mottram (1922, 1923) reported a progressive decrease in the number of platelets in rats fed on A deficient diets. This could be brought back to normal by the addition of the vitamin.

Bedson and Zilva (1923) repeated the above work and found a slight decrease, but did not believe this could be of any significance. Falconer and Peachly (1926), however, demonstrated a decrease, although the variation was very little. Sure and Falconer (1929) found no difference in the leucocyte count but Turner, Loew and Falconer (1932) noticed leucocytosis in 55 per cent of vitamin A deficient rats after xerophthalmia had developed as compared with controls. They also observed an increase in the polymorphonuclears and decrease in the lymphocytes in the A deficient rats. Sure, Walker and Kik (1931) found no significant change in the red and white blood cell counts and hæmoglobin in vitamins A and D deficient rats. Green (1933) reported definite leucocytosis in vitamin A deficient rats having xerophthalmia in about 75 per cent of the animals. The leucocyte count of D deficient rabbits were, however, normal. The pseudo-eosinophils increased in the xerophthalmia group and lymphocytosis occurred in the rachitic animals. Kugelmass and Samuel (1932) working on avitaminosis and blood clotting found that vitamin A deprivation produced a gradual diminution in the fibrinogen content of the blood paralleling the duration of the deficiency without affecting the platelet level, that vitamin B deprivation produced a slight diminution in the fibrinogen content of the blood and that vitamin C was without any appreciable effect, whereas D deprivation diminished the prothrombin and fibrinogen content of the blood, without any appreciable change in the platelet concentration. Mettier and Chew (1934) report that erythrocytes contain vitamin C and avitaminosis C induces grave

cytological alterations in the bone marrow and a retarded formation of erythrocytes. Similar results have also been obtained by Boger and Martin (1935) and by Seyderhelm and Grebe (1935).

Although a decrease in platelets would be quite consistent with the tendency to hæmorrhages which is observed in xerophthalmic rats, the work, reported so far, seems to be insufficient to warrant general conclusions. From these considerations it appears that blood counts do not seem to explain to a satisfactory extent the anti-infective action of the vitamins.

IMMUNOLOGICAL OBSERVATIONS AND VITAMIN DEFICIENCY.

So far no adequate explanation has been offered to account for the greater susceptibility of avitaminic animals to bacterial infection, although the rupture in resistance seems to be definite and determinable. Several factors appear to be of importance in accounting for the failure of animals to resist infection. Suggestive among them would be the presence of degenerative changes in the bone marrow and feeble leucocytosis seen in chronic scurvy guinea-pigs, inability to produce antibodies, reduced bactericidal activity of the blood serum, lowered body temperature and depressed phagocytosis leading to favourable conditions for the growth of micro-organism.

Further, although vitamin deficiency in animals may lead to infection, it is quite conceivable that this effect may be the result of a depressed metabolism that prevents the animal from exerting a normal force to overcome the injurious effects of a small relatively unimportant infection superimposed upon the vitamin deficiency. The attempts to correlate immunological changes with vitamin deficiency have, however, met with questionable success. Werkman (1923) reported that in *B. typhosus* and *Staphylococcus* infections in rats in A and B deficiencies there was a slight but consistent decrease in the phagocytic index. He concluded that the depression in phagocytic activity was not due to failure in opsonin production but was caused by some depressive agent acting on the mechanism of phagocytosis. The lowering of body temperature in B deficiency was suggested as one of the causes.

Findlay and Mackenzie (1922) found no increase in opsonic activity in A and B deficiencies.

The possible effects of vitamin C were studied by Zilva (1922). From his work on the influence of poor nutrition upon the production of agglutinins, complement and amboceptor in guinea-pigs on a scorbutic diet, he concluded that the figures were not different from the normal controls.

Koch and Smith (1925) reported a definite increase in the complement titre in scorbutic over that of the normal period.

Hamburger and Goldschmidt (1922), in a study on human cases, reported that the serum of scorbutic children contains the same amount of amboceptor and complement as that of the healthy controls.

Werkman (1924) found scorbutic guinea-pigs to show no difference from controls in typhoid agglutinin production. Findlay and McLean (1925) showed that the rats lacking in vitamin B for 25 days or more have reduced natural bactericidal power for Staphylococcus. Findlay (1923) has also demonstrated that peritoneal exudates of pigeons lacking in B have a low bactericidal action. Green (1933) reported that rabbits depleted of vitamin A showed a tendency to respond with lower titres than controls to immunisation with *B. typhosus.*

Rabbits on A and B deficient diets, however, showed no change in the serum complement. She also found that vitamin A deficient rabbits exhibit a marked lack of response to immunisation with sheep or ox red cells. The titre of the serum of each control animal was from ten to three hundred times higher than that of the corresponding vitamin deficient rabbit injected at the same time. Vitamin D deficient animals, however, responded normally to sheep red cells.

Several experiments have been carried out to determine the effects of vitamin deficient diets on phagocytosis. Parrino and Scarpulla (1927) fed guinea-pigs and pigeons on vitamin deficient diets and found the phagocytic power of the leucocytes to be reduced and to be restored by vitamin feeding. Findlay and MacKenzie (*loc. cit.*) found that the phagocytic activity of guinea-pigs with chronic scurvy was not increased. Lawrynowicz (1931) confirmed these findings by showing that during scurvy the phagocytic power of leucocytes was reduced and that intraperitoneal injections of an irritant did not cause the formation of a leucocytic exudate as in normal.

DISCUSSION.

Although the manner in which diet affects immunity is but little understood, the presence of an adequate supply of vitamins, more particularly that of the fat-soluble ones, appears to exert great influence. The deficiency of vitamin A has a pronounced effect in lowering the body resistance to certain types of infections both in man and animal. Mackay (1934) undertook a test on a large scale on infants to determine the effects of prophylactic treatment with vitamin A. The results, taken as a whole, indicate a perceptible increase in the resistance of those infants who were given the extra vitamin A to minor infections of the skin. It was found, however, to have little effect on the incidence of general infections. In recent years, evidence has come from another direction of the influence of diet on resistance to infection. Helmholtz (1931, 1932) and Clark (1931, 1932) observed the curative effect of ketogenic diet in many cases of urinary infections. It is true that the success of this therapy is regarded as dependent upon the actual excretion of β-oxybutyric acid (Fuller, 1933) and the acid reaction of the urine, but it would not be surprising if these cereal free diets with high vitamin A contents commonly prescribed for such patients did not possess the power of raising the resistance of the body to infection, apart from the ketogenesis they produce. Evidence of this nature ought to be examined by the extension of the use of such diets to the infection of systems other than the urinary tract. The curative effect on dental caries of diets devoid of cereals and rich in fat-soluble vitamins has been pointed out by Mellanby and Pattison (1932). The best form of diet for combating sepsis may prove to be a combination of high vitamin qualities, especially of low cereal and high fat-soluble vitamin content, with a definite ketogenic action. The effect of an increase in the green vegetables and the reduction of the cereal intake on the resistance of herbivorous animals to infection is undoubtedly marked [Glenny and Allen (1921), Boock and Trevan (1922)]. This may well indicate a reaction in which the increased carotene of the vegetable plays not only a part, but an important part in combating infection.

Webster and Pritchett (1924) in an effort to demonstrate the effect of diet on host susceptibility to infection and intoxication found that mice fed on McCollum's complete diet were more resistant to mouse typhoid infection,

mercury bichloride intoxication and botulinus toxin than those fed on poorer diet.

Thus the evidence obtained from the above observations shows that the cell plays an important rôle in antibody production and resistance to infection. The findings of Orr, Macleod and Mackie (1931) who found that natural antibodies are influenced by nutritional factors lend further support to this view.

It may be objected that in this discussion too much stress is laid on the positive experimental and clinical results, and not sufficient on the negative results of the clinical investigations made since vitamin A has been described as an anti-infective agent. Such investigations in which vitamin A therapy has proved to be ineffective include the following: (1) Barenberg and Lewis (1932) on respiratory infections in infants; (2) Sutliff, Place and Segool (1933) on otitis media complicating scarlet fever; (3) Wright, Frosst, Puchel and Lawrence (1931) on the common cold in infants; and (4) Orenstein (1932) in pneumonia.

It may be said that, on account of the positive evidence given above, negative results only show that our knowledge is still imperfect, and not that the problem is an unprofitable one to pursue further.

SUMMARY.

1. The evidence for the decreased resistance of vitamins A and D depleted animals to infection seems to be convincing. The infection resisting values of B and C are still questionable.

2. The observations on blood show increase in pseudo-eosinophils in A deficiency and lymphocytosis in D deficiency.

3. The results of immunological studies reveal that A deficient rabbits exhibit a marked lack of response to immunisation. There seems to be, however, little change in the production of complement and natural hæmolytic antibodies in the sera on a general deficient diet.

It may be remarked that much remains to be done in order to establish in a more precise manner the relationship between nutritional deficiences and susceptibility to many diseases. There seems no doubt that a diet of biologically high value rich in fat-soluble vitamins considerably helps in increasing the resistance to infection. The existing gaps, however, need filling up and demand extensive investigations, both experimental and clinical.

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SOME PHYSICO-CHEMICAL FACTORS AND THEIR RELATIONSHIP TO PROTEIN FRACTIONS, BLOOD CELLS AND PARASITE COUNTS, IN THE BLOOD SERA OF MONKEYS INFECTED WITH *PLASMODIUM KNOWLESI**.

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THE rôle of the physico-chemical factors in elucidating the changes brought about in the body during the course of a disease is being increasingly recognised. It is possible that a more extensive knowledge of these factors in conjunction with the biochemical changes and the variations in blood cell element, if obtained from the same animal, might be of great value in explaining some of the anomalies met with at present. Since no such data, as far as the author is aware, are available, observations on the blood sera of monkeys during the normal, incubation and disease periods on pH, refractive index, surface tension, specific gravity, protein fractions, and blood cell and parasite counts are presented in this paper.

The common brown monkey, *Silenus rhesus*, was used in these experiments. Apparently healthy animals of average size were selected. Observations were taken for about a week, when the monkey was in a normal state of health. The animal was then infected with *Plasmodium knowlesi* by blood inoculations from another monkey showing parasites in its peripheral blood. These observations were continued during the incubation and the disease periods till death supervened. All these observations were taken on the same sample of blood drawn from the monkey and the results are shown in Tables I, II and III.

1. pH OF THE BLOOD.

The pH of blood was determined by the glass electrode method, devised by Kerridge (1925). It is especially suitable for biological fluids, particularly

* These observations were completed in 1932, but due to the author's absence from these laboratories the results could not be published earlier.

where the quantity available is small. Moreover, the same blood can further be used for other estimations, since it is not affected chemically in any way. The glass electrode is as accurate (within the pH range of biological significance) as the hydrogen electrode, is as rapidly operated as the quinhydrone electrode and is more widely applicable than either of the two (Mirsky and Anson, 1929). Furthermore, Stadie, O'Brien and Laug (1931) believe that the glass electrode gives a degree of accuracy not achievable by hydrogen electrode.

The potential difference of the glass electrode is measured first when it contains a solution of known pH (*e.g.*, 0 05 M potassium hydrogen phthalate). The pH is observed again when the solution of unknown pH is added to the cup of the electrode. The unknown pH is then calculated by the formula given by Kerridge (*loc. cit.*). Any potential due to the glass itself does not affect the final results.

Considerable difficulty was met with in the beginning in not being able to obtain reproducible results. When the tip of the junction tube filled with saturated KCl dips into the cup of the glass electrode, the KCl being heavier than water flows down to the glass membrane, where possibly it exerts an influence in constantly changing the potential difference. This difficulty was, however, overcome by joining an agar-KCl tip to the end of the bridge.

When not in use the glass electrode was kept dipped in distilled water.

An analysis of the figures shows that, during the normal period, the range of pH variation is from 7 326 to 7 389, with average values of 7 367 for monkey No. 32; 7 369 for monkey No. 33 and 7 350 for monkey No. 44. The pH during the incubation period ranges from 7 252 to 7 388 with an average of 7·347 for monkey No. 32; 7 356 for monkey No. 33 and 7 326 for monkey No. 44. During the disease period the values vary from 7 055 to 7 375 with an average of 7 214, 7 264 and 7 206 for monkeys Nos. 32, 33 and 44 respectively.

It is obvious from these observations that during the incubation period the pH is but little affected, while the decrease is more marked during the disease period and more especially when the parasite count is at its maximum.

2. ANAL TEMPERATURE CHANGES.

The anal temperatures in the monkeys varied from 100 0° to 104 0°F. Considerable variations were observed between the morning and the evening temperatures, without any apparent reason. The temperature record therefore did not seem to give any indication of the severity or otherwise of the disease.

3. REFRACTIVE INDEX OF THE SERUM.

The estimations were made with Abbe's refractometer at 20°C. Clear sera only were used.

The results indicate that during the incubation period the refractive index does not show any variations compared to the normal, but that there is a slight increase, persistently observed during the disease period. Segale (1912) and Zunz and La Barre (1922) record an increase of the index in acute anaphylactic shock and the latter authors (1922*a*) report a similar rise in anaphylactoid shock as well. Sinton, Orr and Ahmad (1928) found a rise in the index in human malarial patients during the rigor, compared to the values taken before and after the rigor.

4. SURFACE TENSION OF THE SERUM.

The estimations were made by Du Nouy's apparatus (1922) at 20°C.

It will be observed from the results that there is a slight fall in the surface tension during the incubation period compared to the normal, but the fall is more marked during the disease period, especially when the parasitic infestation is very high. These results are in keeping with those of Sinton, Orr and Ahmad (*loc. cit.*) in malarial paroxysm.

Other observers have also found that the surface tension of pathological sera is, in many cases, slightly lower than that from the normal persons. Such changes have been observed by Chopra and Chaudhuri (1928) in kala-azar and tubercular patients.

5. SPECIFIC GRAVITY OF SERUM.

The specific gravities of the clear sera were determined by a micro-pykrometer. During the time these observations were made the room temperature varied from 20° to 22 5°C.

The specific gravities of the sera of these monkeys, as is obvious from the tables, do not show any variation from the normal period.

6. PROTEIN FRACTIONS OF SERA.

The observations recorded here were completed in 1932 and since then Chopra, Mukherjee and Sen (1934) have published their experiments on human malaria and Ghosh and Sinton (1935) on monkey malaria. It was not our intention to multiply observations, but since all our estimations were made on the same animal at the same time, which was not done by either group of workers, it was considered advisable to publish these results in the hope that some investigator might find them of help.

The serum proteins were estimated by the refractometric method of Robertson (1918) and the temperature of the Abbe's refractometer was maintained at 20°C. by circulating water with an accuracy of $\pm$ 0·2°C.

It will be seen from Tables I, II and III that the non-protein nitrogen does not show any variations during the incubation and the disease periods compared to the normal. The total proteins showed lower average values during the disease period compared to the averages of the normal and incubation periods. There is, however, a noticeable decrease during the disease period in the amount of albumin with increase in globulin. These changes are specially marked when about more than 50 per cent of the red blood cells are parasitised, and the animal is expected to pass black-water urine. These changes result in a marked increase in the globulin-albumin ratio, especially when the parasite infestation is very heavy. During the incubation period, however, this ratio does not differ much from the normal period.

These observations appear to be in line with the findings of Ghosh and Sinton on monkey malaria and Chopra *et al.* on human malaria.

Hurwitz and Meyer (1916) and Hurwitz and Whipple (1917), however, reported that in bacterial infections there was a change in the globulin-albumin ratio with an increase in globulin. They were also successful in producing these effects by the injection of either living or dead organisms and by bacterial endotoxins. The protein variations in the malarial infections, therefore, cannot be considered as specific in nature.

TABLE

Monkey

Showing changes in the physico-chemical factors, protein fractions and blood disease

Date.	Period.	Temperature.		pH of blood at 38°C.	Refractive index of serum at 20°C.	Surface tension of serum at 20°C. in *Dynes.*	Specific gravity of serum.	Non-proteins per cent
		10 A.M.	4 P.M.					
12-6-32	Normal	102·2	100·2	7·384	1·3500	82·55	1·0263	1·5
14-6-32	"	101·4	100·8	7·383	1·3499	83·00	1·0264	1·5
16-6-32	"	100·4	102·2	7·388	1·3500	82·70	..	1·5
18-6-32	"	102·2	100·4	7·354	1·3500	81·10	..	1·5
21-6-32	"	101·0	104·8	7·326	1·3499	82·05	1·0271	1·5
23-6-32	Incubation.	100·4	100·0	7·367	1·3500	81·00	1·0291	1·5
25-6-32	"	100·4	100·0	7·328	1·3492	81·05	1·0270	1·6
27-6-32	Disease	101·0	101·0	7·225	1·3498	80·00	1·0270	1·5
28-6-32	"	102·8	102·6	7·220	1·3508	79·50	..	1·6
29-6-32	"	102·4	103·0	7·212	1·3504	78·75	1·0290	1·6
30-6-32	"	103·0	102·8	7·198	1·3502	78·00	1·0282	1·5
Average values during:—								
(*i*) Normal period ..				7·367	1·3499	82·28	1·0266	1·5
(*ii*) Incubation period				7·347	1·3496	81·02	1·0280	1·55
(*iii*) Disease period ..				7·214	1·3503	79·06	1·0281	1·55

I.

No. 32.

cell and parasite counts in monkey malaria during the normal, incubation and periods.

Protein fractions.				Blood cell counts.			
Albumin, per cent.	Globulin, per cent.	Total protein per cent	Globulin-albumin ratio.	White blood cells per c.mm.	Red blood cells per c.mm. (*in millions*).	Parasites per c.mm	Remarks.
4·25	3·71	7·96	0·87	..	..	..	
4·23	3·67	7·90	0·86	..	..	..	
4·23	3·75	7·98	0·88	15,500	5·7	..	
4·23	3·75	7·98	0·88	14,800	5·4	..	
4·23	3·75	7·98	0·88	18,000	5·6	..	Inoculated with *P. knowlesi* on 21st June, 1932.
..	..	..	..	15,000	5·4	..	
4·33	3·86	8·19	0·89	19,500	5·2	..	
4·23	3·66	7·89	0·86	22,000	4·5	10,000	Parasites appeared in peripheral blood on 27th June, 1932.
4·4	3·62	8·02	0·82	24,000	3·2	50,000	
4·05	3·8	7·85	0·94	25,000	2·5	1,000,000	
2·82	4·85	7·67	1·7	18,000	1·8	1,500,000	Heavy parasite infestation. Monkey died on 1st July, 1932. Passed black-water urine.
4·23	3·72	7·95	0·87				
4·33	3·86	8·19	0·89				
3·87	3·98	7·85	1·03				

TABLE

Monkey

Showing the physico-chemical factors, protein changes and blood cell and parasite

Date.	Period.	Temperature. 9-30 A.M.	Temperature. 4-30 P.M.	pH of blood at 38°C.	Refractive index of serum at 20°C.	Surface tension of serum at 20°C. in *Dynes.*	Specific gravity of serum.	Non-proteins, per cent.
11-6-32	Normal	100·8	101·4	7·377	1·3498	82·8	1·027	1·5
13-6-32	,,	104·0	101·2	7·355	1·3498	83·5	1·026	1·5
15-6-32	,,	101·0	102·2	7·389	1·3495	82·7	1·028	1·6
17-6-32	,,	103·0	102·0	7·387	1·3498	80·8	1·029	1·5
19-6-32	,,	102·0	101·4	7·335	1·3495	82·9	1·026	1·5
22-6-32	Incubation.	100·8	100·4	7·345	1·3498	83·5	1·027	1·6
23-6-32	,,	100·8	100·8	7·367	1·3495	82·2	1·029	1·5
24-6-32	,,	101·2	101·4	7·388	1·3498	81·8	1·027	1·5
25-6-32	Disease	102·8	100·8	7·289	1·3499	81·9	1·028	1·6
26-6-32	,,	103·0	102·4	7·375	1·3495	80·5	1·029	1·5
27-6-32	,,	101·4	100·8	7·205	1·3505	79·8	1·027	1·5
28-6-32	,,	103·6	101·8	7·065	1·3515	79·2	1·029	1·5
Average values during:—								
(*i*) Normal period ..				7·369	1·3497	82·52	1·027	1·52
(*ii*) Incubation period				7·356	1·3497	82·85	1·028	1·55
(*iii*) Disease period ..				7·264	1·3502	80·64	1·028	1·52

II.

No. 33.

counts in monkey malaria during the normal, incubation and disease periods.

Protein fractions.				Total leucocytes per c.mm.	Red blood cells per c.mm. (*in millions*).	Parasites per c.mm	Remarks.
Albumin, per cent.	Globulin, per cent.	Total protein, per cent	Globulin-albumin ratio.				
4·32	3·65	7·97	0·84	..	5·4	.	
4·45	3·85	8·30	0·86	..	5·5	..	
4·25	3·75	8·00	0·86	15,000	5·2	..	
4·47	3·41	7·88	0·76	16,200	5·8	..	
4·50	3·81	8·31	0·84	14,700	6·1	..	Inoculated with *P. knowlesi* on 19th June, 1932.
4·32	3·65	7·97	0·84	15,500	5·0	..	
4·32	3·65	7·97	0·84	18,300	4·8	..	
4·45	3·85	8·30	0·86	19,800	5·2	7,000	Parasites in the peripheral blood on 24th June, 1932.
3·85	3·78	7·63	0·98	22,000	3·8	25,000	
3·8	4·4	8·2	1·1	24,500	2·7	50,000	
2·6	4·5	7·1	1·5	18,000	2·0	180,000	
2·5	4·8	7·3	1·9	17,000	1·5	1,200,000	The animal died on 29th June, 1932. Autopsy showed enlarged spleen, black-water urine in the bladder.
4·398	3·694	8·092	0·84				
4·32	3·65	7·97	0·84				
3·44	4·26	7·7	1·23				

TABLE

Monkey

Showing the physico-chemical factors, protein changes and blood cell and parasite

Date.	Period.	Temperature. 11 A.M.	Temperature. 3 P.M.	pH of blood at 38°C.	Refractive index of serum at 20°C.	Surface tension of serum at 20°C. in *Dynes.*	Specific gravity of serum.	Non-proteins per cent
18-7-32	Normal	103·5	102·8	7·375	1·3490	83·5	1·026	1·5
19-7-32	"	101·4	101·8	7·328	1·3485	83·0	1·029	1·5
21-7-32	"	100·8	103·4	7·355	1·3488	83·2	1·027	1·5
22-7-32	"	102·6	102·5	7·326	1·3490	82·1	1·027	1·5
23-7-32	"	100·0	100·8	7·389	1·3487	82·2	1·029	1·6
24-7-32	"	102·0	103·4	7·328	1·3485	82·3	1·029	1·5
25-7-32	Incubation.	102·8	102·4	7·311	1·3485	82·5	1·029	1·5
26-7-32	"	101·4	102·6	7·288	1·3499	82·0	1·028	1·5
27-7-32	"	101·8	100·4	7·301	1·3498	82·0	1·027	1·5
28-7-32	"	102·4	101·4	7·387	1·3499	82·1	1·026	1·6
29-7-32	"	103·6	101·8	7·295	1·3495	82·0	1·026	1·5
30-7-32	"	102·4	101·3	7·376	1·3499	82·0	1·028	1·5
31-7-32	"	100·4	101·4	7·252	1·3499	82·2	1·029	1·6
1-8-32	Disease	102·8	100·0	7·248	1·3498	81·8	1·029	1·5
2-8-32	"	101·6	104·0	7·275	1·3500	81·2	1·028	1·6
3-8-32	"	102·4	101·4	7·201	1·3508	79·8	1·028	1·5
4-8-32	"	103·2	101·8	7·055	1·3510	79·2	1·027	1·5

Average values during:—	pH	Refractive index	Surface tension	Specific gravity	Non-proteins
(*i*) Normal period ..	7·350	1·3487	82·72	1·028	1·52
(*ii*) Incubation period	7·326	1·3496	82·1	1·027	1·52
(*iii*) Disease period ..	7·206	1·3503	80·84	1·028	1·54

7. BLOOD CELL AND PARASITE COUNTS.

The erythrocyte and total leucocyte counts were made by the hematocrit method and the parasites by Sinton's fowl cell method (1924).

Tables I, II and III show that the total number of leucocytes varies between 13,800 and 18,000 during the normal period. After the monkey has

III.

No. 44.

counts in monkey malaria during the normal, incubation and disease periods.

Protein fractions.				Total leucocytes per c.mm.	Red blood cells per c.mm. (*in millions*).	Parasites per c.mm	Remarks.
Albumin, per cent.	Globulin, per cent.	Total protein, per cent	Globulin-albumin ratio.				
4·5	3·5	8·0	0·77	..	5·1	..	
4·3	3·8	8·1	0·88	..	..	..	
4·3	3·9	8·2	0·88	..	..	..	
4·3	3·5	7·8	0·81	14,700	5·8	..	
4·3	3·5	7·8	0·81	16,500	5·4	..	
4·4	3·8	8·2	0·86	13,800	6·2	..	Inoculated with *P knowlesi* on 24th July, 1932.
4·7	3·8	8·5	0·81	18,000	5·7	..	
4·1	3·3	7·4	0·82	..	..	..	
4·1	3·3	7·4	0·82	..	..	..	
4·0	3·5	7·5	0·87	20,000	5·2	..	
4·2	3·2	7·4	0·76	..	..	..	
4·3	3·6	7·9	0·83	..	..	..	
3·9	3·7	7·5	0·92	25,000	5·0	5,000	Parasites appeared i the peripheral blood o 31st July, 1932.
3·3	4·4	7·7	1·3	28,000	4·8	12,000	
3·2	4·5	7·7	1·4	32,500	3·9	75,000	
3·1	4·8	7·9	1·5	25,000	3·2	235,000	
3·1	5·2	8·3	1·7	25,500	2·5	1,500,000	About 50 per cent of th cells were infected. Died on 5th August 1932, showing enlarged spleen. Passed black water urine.
4·35	3·66	8·01	0·84				
4·23	3·45	7·68	0·81				
2·24	4·5	7·74	1·4				

been infected, the number increases considerably till the parasite infestation reaches a peak, whereafter in two cases a considerable fall in the leucocytes was observed, though it is much less marked in the third case.

The red blood cells vary between 5·1 and 6 2 million during the normal period. There appears to be no change in their number during the incubation period, but at the peak of infection the number falls down to about 1 5 million.

The parasite count reaches about 1·5 million at the height of infection when the animal passes black water and dies.

The observations on the total leucocyte and erythrocyte counts are in conformity with the findings of Bilimoria (1931) in normal monkeys and with those of Malamos (1934) in monkeys infected with *P. knowlesi* during the normal and disease periods.

SUMMARY AND CONCLUSION.

Observations on pH, refractive index, surface tension, specific gravity, anal temperature changes, protein fractions, leucocyte, erythrocyte and parasite counts are presented during the normal, incubation and disease periods on blood sera of three monkeys infected with *P. knowlesi*. The experimental observations furnish evidence to conclude that :—

1. Anal temperature variations are very wide and do not seem to be of any significance in indicating the severity and progress of the disease.
2. The pH values are slightly affected when the parasitic infestation is very heavy.
3. The refractive index shows no variations during the incubation period compared to the normal, though there is a slight but persistent rise in the index during the acute disease period.
4. Surface tension is considerably decreased during the disease period compared to the normal and incubation periods.
5. No variations are observed in the specific gravity.
6. Most of the protein fractions deviate during the incubation and disease periods compared to the normal. The albumins and total proteins decrease, and globulins increase, resulting in a considerable increase in the globulin-albumin ratio.
7. *Plasmodium knowlesi* infection causes a severe anæmia, the erythrocytes drop in number to about 1·5 million at the height of infection. There is evidence of leucocytosis during the incubation and disease periods, but when the number of parasites increases considerably there seems to be a fall in the number of leucocytes.

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DISSECTIONS OF ANOPHELINE MOSQUITOES IN MYSORE STATE.

In an article entitled 'Infectivity Surveys and Feeding Habits of Anopheline Mosquitoes', by B. A. Lamprell, which appeared in the *Records of the Malaria Survey of India,* Vol. 6, No. 2, June 1936, the following passage occurred (page 218):—

'The 15,000 dissections made by Sweet (1929-30) in Mysore, in which he found not a single infected specimen have also been omitted.. ....'

The reference quoted is given as :—

SWEET, W. C. (1929-30) .. Quarterly Reports, Mysore Department of Health, January 1929—March 1930.

In a recent communication Dr. Sweet points out that the reports made in the quarterly bulletin of the Mysore State Department of Health are to be regarded purely as statements of the amount of work done, and not in any sense as a scientific record of the results of that work. These bulletins were at no time regarded as a scientific publication of the results of work, and infections encountered during dissections were purposely omitted.

The detailed results of the dissections made in Mysore State have been reported under the following references :—

SWEET, W. C., and RAO, B. A. (1931). Dissections of Female Anophelines in Mysore State. *Rec. Mal. Surv. Ind.,* **2**, 4, pp. 655–657.

NURSING, D., RAO, B. A., and SWEET, W. C. (1934). Notes on Malaria in Mysore State. Part VII. The Anopheline Transmitters of Malaria. *Ibid.,* **4**, 3, pp. 243–251.

Editor.

ANOPHELES HABIBI Mulligan and Puri, 1936—A CORRECTION

BY

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AND

I. M. PURI, M.SC., PH.D., F.R.E.S.

A DETAILED description of a new species of *Anopheles* (*A. habibi*) from Quetta, Baluchistan, was published in these *Records* by Mulligan and Puri (1936)*. Unfortunately an attempt to correct a mistake in this paper after the page proofs had been submitted resulted in a serious error appearing in regard to an important diagnostic character of this species, namely, the relation of the length of the anterior forked cell to that of the petiole. **In *A. habibi* the length of the anterior forked cell is about twice that of the petiole†.**

The following corrections should therefore be made in the wording of the original description of *A. habibi**.

(1) On page 68, line 17,

for '(*ii*) Length of the anterior forked cell about equal to that of the petiole',

read '(*ii*) Length of the anterior forked cell about twice that of the petiole'.

(2) On page 69, line 22,

for '*Wings* : Anterior forked cell about half as long as the petiole (1 : 0·55)................',

read '*Wings* : Anterior forked cell about twice as long as the petiole (1 : 0·55)................'.

In *A. claviger*, the species which very closely resembles *A. habibi*, the length of the petiole varies from 0·3 to 0·4 that of the anterior forked cell while in *A. habibi* it is 0 55 of that of the anterior forked cell.

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* *Records of the Malaria Survey of India*, 6, 1, pp. 67–71.

† The petiole is measured from the origin of the *supernumerary* cross vein joining the 2nd to the 3rd longitudinal vein up to the point of branching of the 2nd longitudinal vein.

A MOSQUITO SURVEY OF KARACHI AIR PORT.

BY

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(*Indian Research Fund Association.*)

[30th December, 1935.]

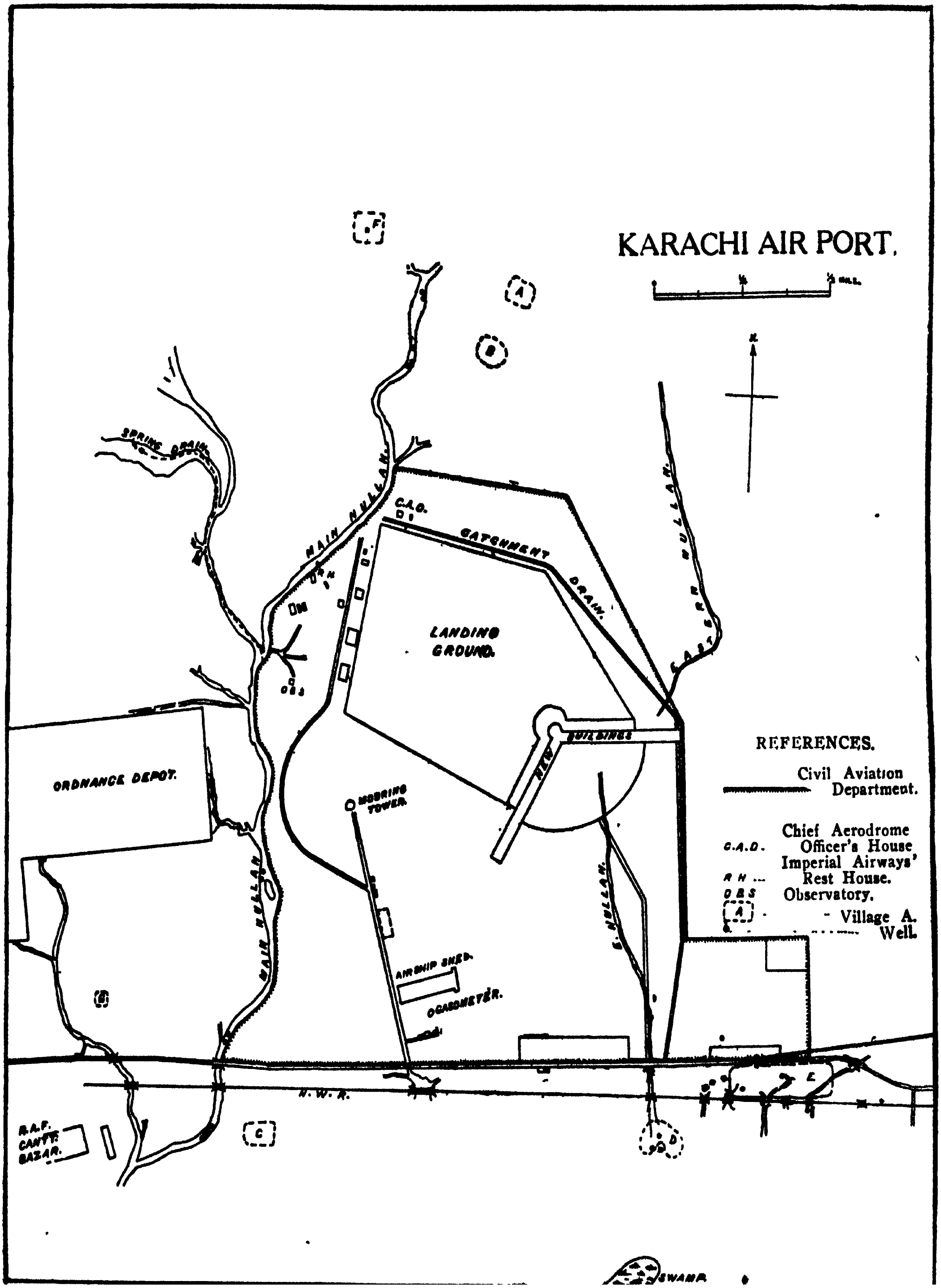
THIS paper records the results of a mosquito survey, held in 1935, of Karachi Air Port and of the area within half a mile. The survey was made to determine the prevalence of *Aëdes aegypti* in view of the possible introduction of yellow fever by air transport. A secondary consideration was the control of malaria. The report is based on two short visits by one of us (E. P. H.) from the 31st January to the 4th February, and from the 29th April to the 1st May; and on a more complete survey by a full staff from the 18th May to the end of October.

GENERAL DESCRIPTION.

Karachi is the first important civil air port for aircraft entering India from the west. It lies ten miles east of Karachi City. Its greatest length from north to south is one and a half miles, and the greatest breadth from east to west is one and three-quarter miles.

In general the surface of the Air Port is flat, with a fall to the south of about forty feet in one and a half miles. The surrounding ground is of the same nature. The western part of the Air Port area has little thick vegetation, but the eastern part is covered with a growth of thorn and cactus. The western boundary of the Air Port is a large nullah ('main nullah') which is joined by a number of tributaries. Another smaller nullah ('eastern nullah') runs through the eastern boundary. To the west lie the Ordnance Depôt and

MAP


KARACHI AIR PORT.
MAIN NULLAH
SPRING DRAIN
C.A.O.
CATCHMENT DRAIN
LANDING GROUND
EASTERN NULLAH
NEW BUILDINGS
ORDNANCE DEPOT
MOORING TOWER
AIRSHIP SHED
GASOMETER
E. NULLAH
N.W.R.
R.A.F. CANTT. BAZAR.
SWAMP
REFERENCES.
Civil Aviation Department.
C.A.D. Chief Aerodrome Officer's House
R H ... Imperial Airways' Rest House.
O B S Observatory.
A - Village A.
Well.

the Royal Air Force Depôt, and to the south-west the Royal Air Force Cantonment Bazar. Surrounding the Air Port are several small villages of huts. The inhabitants of these live by grazing cattle. A few bunds have been built outside the Air Port. They catch rain-water as it flows over the surface, and allow occasional crops to be grown.

The Air Port itself is administered by the Civil Aviation Department of the Government of India, but certain buildings belong to the Air Ministry; these are the mooring tower, the airship shed, and the living quarters which lie between them. The ground to the west of the Air Port is military land under the command of the O. C., Sind Independent Brigade. The remainder of the area, north, east and south, is mainly private property, under no sanitary control. In addition, the North Western Railway owns a narrow strip of land, about twenty yards wide, on each side of the railway track. The Ordnance Depôt is under the sanitary control of the Senior Medical Officer, R. A. F.

SOIL AND METEOROLOGY.

Mosquito prevalence is governed by the nature of the soil, the degree and duration of the rainfall and the direction of the prevailing wind. In the dry season the breeding places are chiefly man-made. They are wells and drippings from stand-pipes. There is also a spring. In the wet season these are supplemented by pools of rain-water.

Soil.—The lower layer is sand and gravel, and allows the passage of water. But the surface layer, from 1 to 3½ feet thick, is composed of a mixture of sand and clay, and is not easily permeable.

This description applies to the greater part of the Air Port area. But in the north-west, outside the Air Port boundary, there is an extensive outcrop of rock, which leads to the appearance on the surface of two springs.

Springs.—One spring lies a mile to the north-west of the north-west corner of the Air Port. Owing to its distance and the direction of the prevailing wind it is probably not dangerous to the Air Port.

A second spring is a serious menace, as it is a favourite breeding place of *A. stephensi*, and lies three-quarters of a mile west of the Chief Aerodrome Officer's house. A narrow *kachcha* drain has been dug, which leads the water down the bed of a tributary nullah to the main nullah, where it is absorbed by the ground. The dry weather flow is about 14,000 gallons in twenty-four hours. The water is brackish; it contains chlorine equivalent to 274 parts of sodium chloride in 100,000 parts of water. The full analysis is shown in Appendix III.

The subsoil water was low throughout our survey. Over the greater part of the area it was never higher than twenty feet below the surface, except in the south-east, where it rose to fifteen feet. We were informed that even after heavy rain it is not likely to exceed ten feet. In the rocky north-western region, however, trial bores showed a different condition. Where grass was growing, water was found at one foot, although this ground was higher than the general level. But when a patch of sandy ground, within fifty yards, was chosen, the bore showed no water till nearly seven feet. The differences are presumably due to irregularities in the subterranean strata of rock, which guide the water to the spring. After heavy rain this ground is likely to become water-logged.

Rainfall (Appendix I, Tables VI and VII).—The average annual rainfall is seven and a half inches, but the volume is very variable from year to year. Nearly the whole falls between the middle of June and the middle of September, the greatest fall being in July.

When heavy rain falls, a large part of the water runs off the surface and is carried away by the nullahs. A small fraction soaks into the ground, and the remainder forms surface pools. As the surface layer of the soil is not easily permeable to water, and as the high humidity does not encourage evaporation, the pools stand for some time. Some disappear after a week or so, a few last for a month or more. If the first rain is reinforced at intervals by showers, there will be no lack of breeding places throughout the rainy season. But if there is little rain, or if all the rain falls within a short period of time, few pools will survive long enough to become a menace. The rainfall of 1935 was scanty, and made it difficult to obtain a clear picture of conditions in an average year.

Wind (Appendix I, Table V).—The prevailing wind is west-south-west. From April to September it is almost continuous, but from October to March winds from other quarters are not uncommon, especially in the morning. Consequently breeding places to the west of the area must be regarded with greater distrust than those to the east. The strength of the wind during the monsoon is that of a moderate to strong breeze in the day, but there is often a lull at night and in the early morning.

WATER-SUPPLY.

The water-supply of the Air Port, Ordnance Depôt and R. A. F. Cantonment Bazar is distributed mainly by stand-pipes. It is continuous and under pressure. There are no wells in these areas. Outside the Air Port the villagers obtain water from shallow wells. We have counted thirty-two of these, of which about twenty-seven held water.

MALARIA.

The incidence of malaria in 1935 may be gauged from the following data :—

1. Evidence of malaria in children living near the Air Port.

TABLE I.

Examination before and after the monsoon period of spleens and bloods of children aged two to ten years living near the Air Port.

Date.	Place.	Number of children.	Percentage with palpable spleen.	Corrected average enlarged spleen.	Percentage showing parasites in blood.
3rd February ..	Villages	36	25·0	10·2 cm.	..
23rd June ..	"	81	21·0	10·1 "	2·5
22nd September	"	98	14·3	10·0 "	2·0
26th June and 6th July.	R. A. F. Cantt. Bazar	101	5·9	..	3·0
22nd and 25th September.	"	94	2·1	..	0·0

The above figures point to a residue of malaria from the previous year, with little fresh infection in 1935.

2. We requested that all those living in the Air Port who complained of fever might be sent to us for diagnosis and treatment. We diagnosed by thick blood films one case of benign tertian and one case of malignant tertian malaria. The number of residents was about one hundred.

3. Malaria in the Royal Air Force. Among Europeans in the R. A. F. Depôt, which lies about two miles west of the Air Port, there were three cases of benign tertian in a strength of about one thousand. Living quarters are screened.

4. Results of dissection of mosquitoes. No gland or gut infections were seen in dissecting 104 *A. stephensi.*

These figures show that malaria in 1935 has been negligible. It is difficult to assess the amount in past years. The Chief Aerodrome Officer, who has lived in the Air Port for several years, says that formerly nearly every one was infected each season. This refers to 'clinical' malaria without blood examination.

Malaria in the R. A. F. Depôt in recent years is shown in Table II.

TABLE II.

Incidence of malaria in the Royal Air Force Depôt (living quarters screened in 1929-30).

Year.	Strength	Number of cases primary	Per 1,000 all.
1926	746	109 4	265 0
1927	752	178 6	372 3
1928	732	24 6	188 5
1929	724	20 9	70 4
1930	743	12 11	48 5
1931	738	9 5	27 1
1932	594	26 9	33 6
1933	574	43 5	54 0
1934	570	31 6	35 1
1935	620	9 6	14 5

The evidence therefore points to a moderate prevalence of malaria in most years.

MOSQUITOES.

Species and seasonal prevalence.

The following species were found :—

Anopheles (*Myzomyia*) *stephensi* Liston, 1901.
,, ,, *culicifacies* Giles, 1901.
,, ,, *subpictus* Grassi, 1899.
,, ,, *pulcherrimus* Theobald, 1902.

Aëdes (*Stegomyia*) *aegypti* Linnæus, 1762.
„ „ *unilineatus* Theobald, 1906.
„ (*Aëdimorphus*) *vexans* Meigen, 1830.
„ (*Mucidus*) *scatophagoides* Theobald, 1901.
„ (*Indusius*) *pulverulentus* Edwards, 1922.
Culex (*Culex*) *fatigans* Wiedemann, 1828.
„ „ *bitaeniorhynchus* Giles, 1901.
„ „ *tritaeniorhynchus* Giles, 1901.
„ „ *vishnui* Theobald, 1901.
Theobaldia longiareolata Macquart, 1838.

The seasonal prevalence is shown in Table III. The visits at the end of January and April were confined to a few days. Consequently the absence of any species from the list on those dates cannot be taken as definite evidence that it was not then breeding.

TABLE III.

Seasonal prevalence of mosquitoes. L = larvae; A = adults.

	31st Jan. to 6th Feb.	29th April to 1st May.	18th to 31st May.	June.	July.	August.	September.	October.
A. stephensi ..	.. ..	L ..	L ..	L A	L A	L A	L A	L A
A. culicifacies ..	.. ..	.. A*	.. ..	.. ..	.. ..	.. A*	.. A*	.. A*
A. subpictus ..	.. ..	.. ..	.. ..	L ..	L A	L A	L A	L A
A. pulcherrimus ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. A	.. A	.. ..
Aëdes aegypti ..	.. ..	.. ..	.. ..	L ..	L ..	L A*	L A	L A
Aëdes unilineatus ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. A	.. ..	.. ..
Aëdes vexans ..	.. ..	.. ..	.. ..	.. ..	L ..	L A	.. ..	.. .
Aëdes scatophagoides ..	.. ..	.. ..	.. ..	.. ..	L ..	.. ..	.. ..	.. ..
Aëdes pulverulentus ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. A*	.. ..	.. ..
Culex fatigans ..	L A	L A	L A	L A	L A	L A	L A	L A
Culex bitaeniorhynchus	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. A*
Culex tritaeniorhynchus	.. ..	.. ..	.. ..	.. ..	.. ..	L A	L A	L A
Culex vishnui ..	.. ..	.. ..	.. ..	.. ..	.. ..	L A	L A	L A
T. longiareolata ..	L ..	L ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..

* less than six specimens.

Adult mosquitoes.

A weekly search for adults was made in all bedrooms and bathrooms. The catches and results of dissection are shown in Table IV.

TABLE IV.

Number of mosquitoes caught in houses or found sheltering out-of-doors, with the results of dissection of Anopheles.

	Caught in houses.		Caught out-of-doors.		Number dissected.	Number infected glands or gut.
	Male.	Female.	Male.	Female.		
A. stephensi ..	28	38	54	70	104	0
A. culicifacies ..	1	6	0	1	4	0
A. subpictus ..	7	3	19	7	10	0
A. pulcherrimus ..	0	10	0	23	20	0
Aëdes aegypti ..	14	39	0	0	..	..
C. fatigans ..	40	54	9	11	..	..

Since the catches in houses were so low, the search was turned in other directions.

A box-trap was set up nightly in the menial lines. No mosquitoes were caught in it. Furthermore, a search of rooms which were not occupied at night produced only one male *Anopheles.*

As a test for the presence of undetected mosquitoes, especially *Aëdes aegypti,* eight bowls of water were maintained in rooms in widely separated parts of the Air Port. Larvæ of *Aëdes aegypti* developed in those placed in the mooring tower, in the observatory, and in a servant's room attached to the Chief Aerodrome Officer's house. This finding must, however, be interpreted with caution. It does not prove that *Aëdes aegypti* was occurring naturally in the Air Port, since the eggs may have been laid by mosquitoes which had escaped from those bred in the laboratory for experimental use. In the course of five months many thousand *Aëdes aegypti* were bred in cages, and, as is almost inevitable, a few escaped. The only justifiable inference from the observations is that this species will maintain itself in the Air Port when clean water is allowed to stand long enough for the development of larvæ and adults.

We also turned our attention to other possible hiding places outside houses, and captured *Anopheles* under railway bridges, in the doors of the airship shed, dry wells, dry brushwood in the bed of a nullah and in a pit of leaf mould.

There are so many possible out-of-door hiding places that anything like an exhaustive search is impossible. The question arises whether adult mosquitoes were not more numerous than was shown by searches in houses, and whether after biting they did not leave the houses to shelter out-of-doors. Against this supposition, there is some evidence that those which sheltered outside living quarters were mainly those which had emerged from the pupæ within the last twenty-four hours. Among 63 *A. stephensi* caught out-of-doors, 33 had no blood in the stomach and showed in the ovaries no development of yelk granules. Of 21 *A. stephensi* caught in houses, only two presented this youthful appearance. If this argument is sound, *A. stephensi* showed no unusual inclination to leave houses after biting, and the number captured in houses represents a fair sample of the *stephensi* population of the Air Port. We therefore conclude that in 1935 the prevalence of mosquitoes was as low

as would be inferred from the catches in bedrooms and bathrooms. This is supported by the statements of residents in the Air Port and R. A. F. Depôt, who noticed far fewer mosquitoes than in previous years, and by the low incidence of malaria.

The explanation is not obvious. Larvæ of *A. stephensi* could always be found, although they were never really numerous. A heavier rainfall would have provided more breeding places, but even under the prevailing conditions there were always many suitable places unoccupied. This suggests that conditions were suitable for larvæ but not for adults. The temperature was never very high, and the relative humidity was about 70 to 85 per cent. These are generally found to be favourable. It may be that deficient rainfall led to a dearth of acceptable breeding places near living quarters, and that the strength and constancy of the prevailing wind increased the hazards of the journey to more distant sites. Moreover, newly hatched adults must often have been swept away without the chance of feeding.

Breeding places.

Potential breeding places in the dry season are the spring, wells, drippings from stand-pipes, valve-boxes, cisterns, sumps, domestic water containers, anti-formicas, fire-buckets, barrels in which grain is soaked to furnish cattle fodder. In the wet season there is, in addition, water lying in pools, borrow-pits and other hollows.

Spring.—The spring and its drain did not always allow breeding. It is not the salinity of the water which is an obstacle. In the laboratory larvæ of *A. subpictus, Aëdes aegypti* and *C. fatigans* lived in spring water as long as controls kept in tap water; in a jar of the water *Aëdes aegypti* laid eggs which developed in the same water into apparently normal adults; while in nature *A. stephensi* flourished in it. But the water has been stocked with larvicidal fish which destroy all larvæ to which they have access.

There is, however, a seepage of water through the grass round the spring, and occasionally pools are found which do not communicate with the drain. They were generally oiled, but as soon as supervision was relaxed they were occupied by *A. stephensi.* The species seemed to have a predilection for this brackish water. The spring must therefore be considered one of the most dangerous breeding places. The same species was also found in the other spring, which lies a mile north-west of the Air Port.

Wells.—*A. stephensi, A. subpictus* and *C. fatigans* bred in wells. *A. stephensi* was found as early as the 30th April. The wells are particularly dangerous, since they persist throughout the year, and allow this species to begin its annual increase before the arrival of the rains.

The sumps are concrete pits which receive sullage water and drippings from stand-pipes. We expected to find larvæ in them, but in fact rarely succeeded, because the water is baled out at short intervals by sanitary coolies. There are, however, two sumps outside the gas-generating plant which are not controlled by these coolies. Larvæ of *A. stephensi, A. subpictus* and *C. fatigans* were collected from them. It is obvious that only constant supervision prevents the sumps from breeding mosquitoes.

Stand-pipes.—From those stand-pipes which are not provided with a sump the drippings collect in a shallow pool. Grass grows up and affords shelter. In this water *A. stephensi* and *A. subpictus* bred regularly.

Valve-boxes.—Many valve-boxes held water constantly, but rarely showed larvæ. *A. stephensi* was found twice and *C. fatigans* once.

The cisterns did not breed mosquitoes. Though special attention was paid to them, one pupa only of *A. subpictus* was found. This is surprising, as in Bombay cisterns are one of the chief breeding places of *A. stephensi* (Covell, 1928).

Domestic water containers are traps rather than nurseries for mosquitoes. In the Air Port itself, the residents collect water from stand-pipes in *chatties, gharras,* etc., after pouring away the residue from the previous day. Outside the Air Port the villagers draw water from wells and store it in similar vessels, which they also are in the habit of emptying daily. Therefore, though mosquitoes may lay eggs in such collections of water, they will only rarely survive to maturity. Occasionally, however, water is stored in receptacles, such as disused oil drums, which are too large to empty conveniently. It was in one of these, in the R. A. F. Cantonment Bazar, that *Aëdes aegypti* was found breeding regularly.

It is interesting to contrast the position in Baba and Bhit Islands, which lie in Karachi harbour. The fisherfolk who live on them buy their water by the gallon from waterboats, and are naturally averse from wasting it. Consequently *Aëdes aegypti* breeds freely in water-barrels in these islands.

Grain barrels.—The pasturage for cattle is poor, and is supplemented by grain soaked in barrels of water. The barrels are in constant use and are emptied daily, and so rarely furnish opportunities for breeding.

Wet weather breeding places are formed by water lying in hollows in the ground, such as borrow-pits, depressions in the beds of the nullahs and dry wells. When not replenished by fresh rain they persist for a variable time, some for a few days, others for a few weeks, and a few for a month or more. The variation appears to be due to differences in the thickness and completeness of the impermeable surface layer of the soil. For example, a pool in the eastern nullah held water for more than six weeks after rain, long after all other surface water had disappeared.

There are also a few special places capable of collecting water.

The gasometer always held a few inches of water between the inner and outer walls. No larvæ were found.

The gas-cooling plant may prove a source of danger. When it is in use, the trough above and the tank below will never be entirely emptied. But during our survey, water never lay in them long enough to allow breeding.

LARVICIDAL FISH.

The fish which live in the spring water were identified by Dr. S. L. Hora, D.SC., as *Lebias dispar* Rüppell. Though they are not known to have been used in India for the control of mosquito breeding, they are worthy of consideration. They take larvæ eagerly and appear to be hardy. We were informed that they have been in the spring for at least four years, that they have increased in numbers, and that the stock has not been replenished. It is however less certain that they are effective in wells. Twenty-five were placed in one well which was swarming with larvæ of *C. fatigans*. The fish lived for a few weeks and the larvæ disappeared, but had returned six weeks from the

day on which the fish were introduced. The surface of the water was twenty-one feet below the ground level.

RELATION OF MOSQUITOES TO DISEASE.

Aëdes aegypti and *C. fatigans* must be considered in connection with the possible advent of yellow fever.

There is no satisfactory evidence that *Aëdes aegypti* occurs naturally in the Air Port, but it has been shown that, when introduced, it can maintain itself when water is allowed to stand. It was constantly found in one place in the R. A. F. Cantonment Bazar, from which the prevailing wind blows towards the Air Port; it breeds freely in Karachi harbour; and it was found in Karachi City by Mhaskar (1913). There is therefore nothing in the local conditions to inhibit it. It is probable that its absence from the Air Port is due solely to the supply of piped water and the consequent avoidance of storage in houses. Nevertheless, with the opportunities offered by the increased population which is planned, it may be expected to establish itself in the Air Port unless definite steps are taken to exclude it.

C. fatigans was shown by Davis (1933) to be capable of transmitting yellow fever in the laboratory. Its epidemiological importance, however, is doubtful. Though it is widely distributed in warm countries throughout the world, no epidemic of yellow fever has yet been attributed to it, nor indeed to any species other than *Aëdes aegypti* with one exception. This was an epidemic in Brazil, where *Aëdes scapularis* was suspected (James, 1935). But if efficient measures are instituted against other mosquitoes, *C. fatigans* should disappear with them.

With regard to malaria, the two dangerous species are *A. stephensi* and *A. culicifacies,* which are well known throughout India as carriers of malaria. That they were not found infected in 1935 is probably due to the fact that the low rainfall did not allow them to breed in sufficient numbers to start an epidemic. The two other species of *Anopheles, subpictus* and *pulcherrimus,* have not been found to transmit malaria in India. There is therefore no reason to fear that they are dangerous in Karachi Air Port.

RECOMMENDATIONS FOR MOSQUITO CONTROL.

The control of mosquitoes in the Air Port involves the control of breeding places outside its boundaries. It will be impossible to combine economy with efficiency unless the whole of the area can be placed under the administration of one man for anti-mosquito work. A Health Officer has been appointed, who is responsible for preventing the appearance of mosquitoes in the Air Port. We strongly urge that he should be made responsible for the control of breeding places adjacent to its boundaries. On the north, east and south, the controlled area should cover half a mile from the Air Port boundary; on the west it could with advantage extend over the military land up to the area under the sanitary jurisdiction of the Senior Medical Officer of the R. A. F. Depôt, with whom the Air Port Health Officer should co-operate.

The principle underlying the following recommendations is that permanent measures are more economical and satisfactory for those breeding places which persist throughout the year, but that temporary measures are indicated for those which appear casually in the rainy season.

An essential preliminary to anti-mosquito work is the clearing of the jungle on the eastern side. At present it is dense enough to conceal breeding places, to prevent evaporation and to offer shelter to adult mosquitoes.

Permanent measures.

Since *Aëdes aegypti* breeds in clean water in and around houses, two measures are needed to control it. The first is the provision of an adequate supply of piped water under pressure, preferably laid on to each house, thus reducing the need for storage to a minimum. The second is regular inspection of all buildings, and especially empty buildings, for the detection of larvæ. In some places a householder who is found to harbour mature larvæ has to pay a small fine on conviction. The knowledge of this greatly increases the ease and efficiency of inspection, and such a system should be instituted if possible.

The precautions taken against *Aëdes aegypti* will control certain breeding places suitable for other species. For instance, a constant water supply under pressure largely obviates the need for cisterns in which *A. stephensi* can breed, and inspection will prevent *C. fatigans* from breeding within houses. But in addition more extensive measures are necessary.

Spring.—The Public Works Department intend to pipe off the water for sanitary use in the new buildings, and will therefore build a concrete collecting box round the spring itself. There remains a grass-covered area of seepage, extending over 250 square yards, in which *A. stephensi* breeds constantly. We have dug drains and sunk trial bores to determine the depth and direction of flow of the water. It seeps into the area from the north and west, and also percolates from below. Depressions should be filled with earth, and subsoil drains discharging into the spring should be laid down (estimated cost Rs. 175).

In the monsoon period the spring may deliver more water than can be carried off by pipes. The overflow will be temporary and variable, and may be dealt with by temporary measures, such as oiling, etc. It should be allowed to escape from the collecting box through one or more horizontal pipes, each fifteen feet long and not more than six inches in diameter. Such a pipe should not allow mosquitoes to penetrate to the water within the box.

The collecting box should have a circular manhole, with a tightly-fitting lid provided with a short cross-bar and padlock.

The full volume of water delivered by the spring will not be required for sanitary purposes, and will not be carried to the new buildings. Thus there will be an overflow even in the dry season. It will be permanent and not very variable, and should therefore be treated by permanent methods. It should be led to the nearest point at which the ground will absorb it. This is in the main nullah, where the water in the present drain is absorbed. Where the pipe line crosses the main nullah a high level overflow should be provided. This consists of a **T**-junction, the upper end of which is turned over so as to discharge directly into the bed of the nullah. The height of the vertical arm will be so calculated as to carry off excess water without causing loss of head, and will discharge it from a height of several feet into the main nullah. Here a pool is likely to form, but the turbulence caused by the water falling from a height will prevent mosquitoes from breeding and the pool from silting up (estimated cost Rs. 50).

Wells.—The only satisfactory method of dealing with wells is to fill them up. Since many of them are in nullahs, the earth used for filling may come from the sides of the nullah to avoid the creation of borrow-pits. The estimated cost is Rs. 5 for each well, or Rs. 160 for all.

Villages.—If the wells are to be filled up, the villages must either be removed or must be provided with an alternative source of water.

An alternative water-supply may be provided in three ways :—

1. Retaining certain of the present wells, fitted with a concrete cover and pump. This is not altogether satisfactory, since cracks developing round the edge of the concrete and round the pump allow the ingress of mosquitoes.

2. Provision of stand-pipes connected with the existing water main. It is doubtful if the Karachi Municipal Corporation would agree to this, as the water-supply of the city is even now insufficient. Moreover, the villagers would have to pay for the water supplied.

3. Sinking of tube-wells. This is the most effective and cheapest method. Trial bores should be sunk, though there is no reason to anticipate difficulty except in the case of village F, where there is the possibility of meeting rock or brackish water. In this event, the tube-well could be placed on the edge of the main nullah, near the position of the well which the village now uses. The estimated cost of a tube-well, with a pump and 1½-inch pipe, including labour, is Rs. 150. Such a well will provide up to 800 gallons an hour. Each of the above methods involves the construction of a concrete pedestal for the pump or stand-pipe, a trough for cattle and a soakage pit for the overflow. The estimated cost of one such outfit is Rs. 50.

The following is the course recommended :—

1. Removal of villages C, D and G.

2. Supply of one tube-well to village F, and another between villages A and B.

3. Removal of village E. It lies across the road from the proposed new subordinate quarters in the Air Port. It is quite innocent of sanitation, and is therefore dangerous to health, apart from the question of filling wells and inspecting huts. Moreover, the children form a reservoir of malarial infection.

The Collector of Karachi has powers to forbid the erection of new buildings on this land, and he should be asked to prohibit those which are not approved by the Air Port Health Officer.

The names of the villages are :—

A. Khan Mahomed Gabole.
B. Ali Mahomed Gabole.
C. No name.
D. Haji Saindino Hingoro.
E. Morio Burro and Gadda.
F. Zigri.
G. No name.

Soakage pits, when properly constructed, have been found in this neighbourhood to work satisfactorily for several years. They should be at least ten feet square and eight feet deep, filled with large stones below and smaller stones above. Surface water carrying silt may be excluded by a layer of sand. The estimated cost of such a pit is Rs. 20.

Stand-pipes.—The drippings from stand-pipes are a perennial invitation to *A. stephensi* and *A. subpictus.* Therefore all stand-pipes should be surrounded by a concrete pedestal which is connected with the main drainage system.

Cisterns.—In Karachi, as in Bombay, cisterns will no doubt be colonised by *A. stephensi* when wells and pools are denied to it. The provision of a constant high pressure water-supply will greatly reduce the number required. Those which are installed should conform to the design prepared by Covell (1928) for Bombay, and those at present in existence should be converted to this type. The points which he stressed are reproduced in Appendix II.

There are at present four cisterns in the mooring tower, one in Imperial Airways' Rest House, and one in the Chief Aerodrome Officer's house. The cost of converting these to the mosquito-proof type is estimated at Rs. 200.

The sewage disposal system of the new administration buildings will probably be by a single septic tank, discharging its effluent through agricultural pipes. The details of this, and of that for the new living quarters, are not yet available. It is desirable that the plans, when completed, should be seen by the Public Health Commissioner.

In the buildings now existing on the western side of the Air Port, the sullage water and urine drain into sumps. Night-soil is collected for incineration. It is not considered practicable to join these to the drainage system of the new buildings. To prevent mosquitoes from breeding in the sumps, and to avoid the danger to health from the open carriage of night-soil, a separate septic tank system should be laid down to include all buildings between the observatory and the Chief Aerodrome Officer's house (estimated cost Rs. 5,000).

The old buildings between the mooring tower and the airship shed belong to the Air Ministry. If they cannot be provided with a septic tank, sullage water and urine should be drained into soakage pits. Four will be required at a cost of Rs. 20 each.

Rainy season.

The methods of treating accumulations of rain-water are permanent drainage or temporary measures.

Subsoil drainage is not likely to be effective. The subsoil water is always low, so that the formation of pools is not due to water-logging. It is due to the relatively impermeable surface layer of the soil, which would prevent water from reaching a subsoil drain. Moreover, such water as did penetrate would be likely to carry down a fine silt to block the drain.

The natural drainage should be encouraged. It carries off a large volume of water, both from the Air Port and from the country to the north. It consists essentially of the main nullah on the west and the eastern nullah.

The main nullah may be left in its present condition. It is true that pools form in its bed after rain, but the cost of providing a *pukka* drain would be out of all proportion to the benefit received.

The eastern nullah is also important. After no more than 0·65 inch of rain on the 17th July it was filled to the brim with swiftly running water. But it is not continuous; at certain points the bed of the nullah rises to the ground level, and the water spreads into a swamp.

At about the middle of its course this nullah crosses the line of a proposed new catchment drain, which is designed to protect the north and east of the Air Port. That part of the nullah which is south of the drain lies inside the Air Port. It will no longer carry off rain-water falling north of the Air Port.

Moreover, much of its course will be obliterated by the new administrative block and by the new road, in connection with which certain drains will be made. It is therefore impossible at present to decide what will be its future importance and the best permanent measures to be applied. In view of the uncertainty, the estimate for this should be postponed to the 1936-37 budget. The sum required is likely to be quite small. For the present the nullah itself, south of the catchment drain, should be left untouched, except for oiling when necessary. However the jungle which surrounds it must be cleared, as it is dense enough to prevent the approach of an oiling gang. Most of it will be cleared by the Public Works Department in connection with the new buildings and road, and we recommend that this department should be asked to complete the work by clearing all dense jungle inside the Air Port boundary. The standard to be reached is that sufficient to allow in all parts the passage of a light hand-cart carrying oiling apparatus.

North of the catchment drain, the jungle must be cleared and those parts of the nullah which are deficient must be canalised. These operations should extend for a mile north of the point where the nullah crosses the catchment drain. The cost of canalisation is difficult to estimate exactly. It may be taken as equivalent to the cost of a new earthern drain, 3 $\times$ 3 feet and a quarter of a mile long. This is Rs. 200. The area to be cleared is equivalent to a strip a mile long and 220 yards wide on each side of the nullah. For rough clearing by machinery, which will be available, the cost without stumping is Rs. 20 an acre, or Rs. 3,200 in all. When the jungle alongside the nullah had been cleared, there will only remain a few widely separated thickets, amounting in all to about four acres. They may be cleared by hand at Rs. 30 an acre, or a total of Rs. 120.

Much of the rain which falls on the Air Port does not drain into these nullahs, but runs over the surface towards the south, and has been known to flood the airship shed. To deal with this, *kachcha* drains have been dug round the landing ground and past the airship shed. A more complete system of surface drains will be constructed when the new buildings are undertaken. To prevent mosquito breeding they should be robust, so graded as not to allow stagnation of water, and should discharge well clear of the Air Port.

In the extreme south-west corner of the Air Port, a *kachcha* road runs eastwards from the main road. It is sunken, and after rain holds water to a depth of two or three feet. We were informed that the portion inside the Air Port boundary will be filled in, and that a drain will be dug inside the boundary to carry off the water from the road.

About a quarter of a mile south of the Air Port boundary is a swamp which collects water from the surrounding land. The natural line of drainage is westwards into a nullah which discharges into the Malir river. The swamp is now used for watering cattle, but presumably they will depart when the villages are moved. It should be connected with the nullah by a drain 400 yards long, at an estimated cost of Rs. 180. The earth removed in making the drain may be used to fill any holes or depressions which are not satisfactorily drained.

There remain a number of borrow-pits, dry wells and other cavities which collect water. Most of them are too deep for drainage and should be filled with old tins and other rubbish from the incinerators, and with earth removed

in canalising the eastern nullah. Two of the pits communicate with this nullah, so that after rain they are filled with water to a depth of as much as ten feet. When the work of canalising the nullah is undertaken, these communications should be blocked and the pits filled.

Gas-generating plant.—The gasometer can be drained and should therefore not be allowed to hold water.

The plant includes two large concrete sumps. They are not now in use, and it is uncertain when they will be required. They may be filled with earth, which can be removed if the sumps are again taken into use. The estimated cost is Rs. 15 for each.

The tank under the cooling plant and the trough above it may be treated with cresol when it is found that rain-water is lying in them.

Airship shed and hangars.—The structures of the hangars and of the door of the airship shed contain only a few places where water may collect. If in future years they are found to breed larvæ, it will be a simple matter to fill the cavities with cement, or to bore holes to allow the water to escape.

Rain-water pools.—When the above measures have been taken, the problem is reduced to that of a moderate number of rain-water pools. It is a problem peculiarly suited to temporary larvicidal methods, because the rainy season is short and variable, the annual fall is never heavy and sometimes very light, and because arrangements have been made for adequate supervision. Oil rather than paris green is indicated, because it is desirable to destroy culicines and because waste oil from aeroplanes is available. In addition, temporary drains may be dug or pools may be pumped dry as circumstances indicate. In some pools vertical drainage will perhaps prove a saving of labour. A pit may be dug in the bottom of the pool and filled with stones, to allow the water to reach the lower pervious layer of the soil. The pit should be broad and deep. If it does not become silted up, it will form a semi-permanent drain.

New buildings.

Work began on the new buildings in the summer of 1935. Recommendations for preventing mosquito breeding were submitted to the Public Health Commissioner with the Government of India in a report on the conference of the 29th April, 1935, which was held at the Air Port to discuss these buildings. A summary of these recommendations is reproduced in Appendix II. It is desirable that those departments which are responsible for creating potential breeding places should bear the cost of rectifying them.

SUMMARY.

1. A survey of Karachi Air Port was made in 1935 to determine the prevalence of *Aëdes aegypti* and *Anopheles*.
2. The prevalence of mosquitoes is governed by the nature of the soil, the rainfall and the prevailing wind.
3. The lower layer of the soil is pervious to water. The surface contains clay and is less easily permeable. The subsoil water is low.
4. The annual rainfall is light and variable; the average is seven and a half inches. The greater part falls between June and September.
5. The prevailing wind is west-south-west.

6. Malaria in 1935 was negligible, but there is evidence of a moderate incidence of malaria in recent years.

7. A complete list of mosquitoes captured, with their seasonal prevalence, is given. *Aëdes aegypti* was found breeding near the Air Port. There is no natural barrier to its invasion of the Air Port. A few *A. stephensi* and *A. culicifacies* were found. No infected mosquitoes were caught.

8. *Aëdes aegypti* does not breed naturally in the Air Port, probably because there is a supply of piped water.

9. In the dry season *A. stephensi* breeds chiefly in a spring of brackish water, in wells and in drippings from stand-pipes. In the rainy season it also breeds in pools of rain-water.

10. The larvicidal fish, *Lebias dispar,* has been used with considerable success.

RECOMMENDATIONS.

(*A*) *General.*

(*a*) Air Port Health Officer should have control of mosquito breeding over adjacent land.
(*b*) All water-supply to be piped and under continuous pressure.
(*c*) Regular inspection of buildings for larvæ.
(*d*) Fines for occupiers of houses in which mature larvæ are found.

(*B*) *Special, with estimates of cost.*

	Rs.
(*e*) Spring. Subsoil drainage of seepage	175
High level overflow	50
(*f*) Wells, filling	160
(*g*) Villages; two tube-wells	400
(*h*) Stand-pipes to be connected with main drainage.	
(*i*) Cisterns; converting six cisterns	200
(*j*) Sewage disposal; Public Health Commissioner to see plans.	
Septic tank for existing buildings	5,000
Four soakage pits for Air Ministry buildings ..	80
(*k*) Eastern nullah; canalisation	200
Jungle clearing by machinery	3,200
(*l*) Jungle clearing (apart from eastern nullah).	
P. W. D. to be asked to complete the clearing of all dense jungle inside the Air Port.	
Clearing by hand of four acres	120
(*m*) Swamp south of Air Port; drainage	180
(*n*) Gas-generating plant; filling two sumps	30
(*o*) Temporary pools to be oiled.	
(*p*) Other measures as detailed in the report to the Public Health Commissioner	3,350
	13,145

(*q*) For 1936-37 budget
Work on eastern nullah inside Air Port less than .. **500**

ACKNOWLEDGMENTS.

We wish to record our thanks for the friendly co-operation we received at Karachi from all quarters; and especially to Lieutenant-Commander W. H. Watt, R.N.R., Chief Aerodrome Officer, to Mr. D. Chakravarti, B.SC., D.I.C., Aerodrome Officer, and the staff of the Air Port; to Mr. C. J. Rae, B.E., M. (Eng.), Executive Engineer, Sind Central Division, C. P. W. D., for his invaluable assistance with estimates and other engineering problems; to Squadron-Leader T. V. O'Brien, M.B., CH.B., R.A.F., Senior Medical Officer, Royal Air Force Depôt, Karachi; to Mr. T. Alfred, B.A., Mukhtiarkar of Karachi, for much essential information, and to Dr. I. M. Puri, M.SC., PH.D., F.R.E.S., Entomologist, Malaria Survey of India, for confirming the identifications of mosquitoes.

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APPENDIX I.

Table V.

Karachi Air Port; percentage frequency of surface winds at 9 a.m. and 7-30 p.m., I. S. T., and mean daily velocity. Five years' observations.

	9 a.m.									7-30 p.m.									Mean velocity.
	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.	
January ..	38	37	4	1	0	1	3	7	9	2	20	9	2	2	24	33	7	2	6·2 m.p.h.
February ..	27	37	5	0	0	1	8	6	16	1	11	6	1	1	31	44	3	1	6·4 „
March ..	18	16	3	3	1	5	31	8	15	0	0	1	0	1	37	57	5	0	7·6 „
April ..	8	5	1	0	1	11	57	12	6	0	0	0	1	0	46	52	1	0	10·1 „
May ..	1	1	1	1	0	16	68	10	3	0	0	1	0	0	48	48	3	0	12·0 „
June ..	0	1	2	0	1	31	63	3	0	1	0	1	0	3	57	39	0	0	13·3 „
July ..	1	3	2	1	1	29	57	7	0	0	1	0	0	1	52	44	3	0	13·5 „
August ..	0	0	0	0	1	21	72	7	0	0	0	0	0	0	48	50	1	0	12·9 „
September	2	2	1	0	0	16	67	9	4	1	1	1	0	1	46	47	2	1	11·9 „
October ..	·23	21	2	1	0	4	25	14	10	1	4	1	1	3	36	45	7	2	6·6 „
November	48	35	1	1	1	0	1	3	11	3	13	8	1	1	26	40	7	1	5·3 „
December	44	38	5	0	0	0	1	3	10	3	18	12	3	2	22	31	5	5	6·0 „

Table VI.

Annual rainfall in inches in Karachi Harbour (Manora) for 25 years, compiled from the annual summaries of the India Weather Review.

	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Total for year ..	6·46	7·09	12·63	4·84	3·17	13·45	9·34	2·26	21·87	5·63	2·04	3·39	1·97
Rainy days* ..	7	8	10	9	4	14	14	5	16	13	6	8	5
Heaviest fall ..	2·40	3·42	6·08	..	1·87	4·25	1·51	0·71	5·65	0·73	0·55	1·45	0·77

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	Mean
Total for year ..	16·90	1·99	5·57	3·69	4·38	20·04	8·19	2·39	4·13	16·07	0·73	12·78	7·64
Rainy days* ..	10	2	8	9	7	11	10	5	8	12	2	13	..
Heaviest fall ..	5·41	1·35	2·64	1·15	1·06	8·11	1·91	0·78	1·42	7·86	0·21	5·70	..

* Days on which 0·10 inch or more rain fell.

TABLE VII.

Monthly rainfall at Karachi Air Port.

	1929	1930	1931	1932	1933	1934	1935
January ..	0·01	0·27	0·05	0·06	0·04	0·0	..
February ..	0·0	0·0	0·14	0·0	0·03	0·0	..
March ..	0·0	0·0	0·17	0·0	0·0	0·02	..
April ..	0·0	0·0	0·0	0·0	0·09	0·0	..
May ..	0·0	0·0	0·0	0·0	1·31	0·0	0·0
June ..	0·0	1·28	0·05	0·0	0·0	2·10	0·0
July ..	7·48	11·79	0·22	7·99	13·99	4·58	1·04
August ..	0·37	0·14	0·06	1·29	2·98	0·28	0·30
September	0·0	0·04	0·0	0 07	2·38	0·01	0·15
October ..	0·0	0·0	0 0	0·0	0·0	0·0	0·02
November	0·98	0·0	0·0	0·0	0·0	0 0	..
December	0·67	0·0	0·0	0·0	0·0	0·18	..
TOTAL ..	9·51	13·52	0 69	9 41	20 82	7·17	..

TABLE VIII.

Mean monthly temperatures and relative humidities at Karachi Air Port, based on six years' observations.

	TEMPERATURE. Mean daily.		RELATIVE HUMIDITY Mean.	
	max.	min.	a.m.	p.m.
January ..	77·5	50·0	50	43
February ..	81·2	54·5	61	53
March ..	89·1	61·8	64	57
April ..	95·2	71·1	63	61
May ..	94·9	77·5	69	71
June ..	94·1	81·9	71	75
July ..	91·1	81·1	77	77
August ..	88·1	78·9	78	76
September	89·8	76·3	74	76
October ..	94·8	68·7	59	55
November	89·2	59·7	51	51
December	81·1	53·2	55	49

The figures in Tables V, VII and VIII were supplied by the courtesy of Dr. S. K. Pramanik, M.SC., Meteorologist, Karachi.

APPENDIX II.

Schedule of requirements for mosquito-proofing the proposed new buildings at Karachi Air Port.

Cisterns. All mosquito-proofed, of the type designed by Lieut.-Col. G. Covell (1928) for use in Bombay. Round manhole, tight-fitting lid, short cross-bar, no inlet pipe through manhole. Check nuts to inlet pipes, etc. Perforated brass caps to overflow pipe. Large cisterns may be covered with reinforced concrete or iron plates, never corrugated iron. If not easily accessible, to have permanent iron ladders fixed to facilitate inspection. No wire gauze to be used to mosquito-proof cisterns.

W. C. cisterns. No aperture in cover.

Automatic flushing cisterns for urinals. No aperture in cover.

Wells. Presumably will not be needed.

Water. Continuous high pressure supply through 24 hours and throughout the year.

Stand-pipes. On a raised cement pedestal connected with the main drainage.

Cement floors. If covered with water during construction, the water should contain 1 in 2,000 cresol

Cellars. Undesirable. If essential, to be constructed in such a way as not to permit water to percolate and stand in them.

Fire-buckets. Undesirable.

Borrow-pits. Should not be formed. If unavoidable, to be properly drained at the time of construction.

Screening to all living and night duty quarters, in accordance with Article 38 of the International Sanitary Convention for Aerial Navigation.

Sumps to have cement concrete covers.

No open garden tanks, tubs or cisterns.

Road watering and fire hydrants. Valve-boxes to be covered with a close-fitting lid and to be provided with a lock.

APPENDIX III.

Composition of spring water on the 20th June, 1935.

Analysis by Dr. N. D. Kehar, D Sc., Biochemist, Malaria Survey of India.

Physical examination—

Colour in 6-inch column ..	slight yellow tint.
Turbidity	faint, a little flocculent matter.
Odour	none.
Taste	flat.
Sulphuretted hydrogen ..	none.

Chemical examination—

Total solids	466·8 parts per 100,000 parts of water.
Hardness :	
Total	23°.
Permanent	13·8°.
Temporary	9·2°.
Chlorine	166 parts per 100,000.
Equivalent of sodium chloride ..	273·9 parts "
Saline ammonia	0·088 " "
Albuminoid ammonia ..	0·048 " "
Nitrite nitrogen	present in infinitesimal amount.
Nitrate nitrogen ..	0·145 parts per 100,000.
Sulphates	1·6 " "
Phosphates	traces.
Carbonates	8·8 parts per 100,000.
Calcium	99 " "
Magnesium	57 " "
Potassium	187 " "
Sodium	121 " "
Iron (ferric)	traces.

Records of the Malaria Survey of India, 6, 4, December, 1936.

SOME NOTES ON THE CARE, TRANSPORTATION, AND USE OF *GAMBUSIA AFFINIS* UNDER INDIAN CONDITIONS.

BY

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[15th May, 1936.]

INTRODUCTION.

THE purpose of this paper is to place in the hands of the practical malariologist in India some information with regard to the top-feeding minnow, *Gambusia affinis*, for use in antimalaria work. In 1929 a stock of *Gambusia* was established at the Ross Field Experimental Station for Malaria, Karnal, and, within recent years, the demands for supplies of this larvicidal fish have increased to such an extent that various health authorities are now being advised to maintain their own hatcheries from which their local demands may be met. In addition to requests for supplies of *Gambusia* we have been inundated with inquiries regarding the care and use of these fish, and it is hoped that the information given in this paper will provide answers to some of the commoner questions referred to us.

Special attention has been given to methods for rearing, maintaining, and transporting *Gambusia affinis* under Indian conditions. It is not claimed that the measures described are the only, or even the best, ones available, but they have, in our hands, given eminently satisfactory results*.

GAMBUSIA AFFINIS AS A LARVICIDAL FISH.

Covell (1935) gives the following requirements for larvicidal fish :—

(1) They must be small, so that they can get about in shallow water, among weeds, etc.

* Readers who are especially interested in the use of larvicidal fish are referred to a pamphlet entitled 'The Use of Fish for Malaria Control', published by the International Health Board of the Rockefeller Foundation, New York, 1924.

(2) They must be hardy, and flourish in both deep and shallow waters.
(3) They must be able to breed freely in confined water areas.
(4) They must be able to stand transport and handling.
(5) They must be difficult to catch, and able to escape their natural enemies including man.
(6) They must be absolutely worthless and insignificant as food.
(7) They must be top-feeders and carnivorous.

Gambusia affinis appears to satisfy these requirements in a large degree, and is probably more suitable for antimalarial purposes than any other species of fish so far investigated. Other varieties of fish which prey on mosquito larvæ, and which are indigenous to India, will not be considered in this paper. Covell (1935) has pointed out that 'it has sometimes been argued that where indigenous larvicidal fish are present, these should be utilised in preference to species imported from other countries. The experience gained with *Gambusia,* however, has led to a modification of this view. It seems that the local fish, after the space of centuries, have reached a balance with regard to their natural enemies, and their numbers cannot be artificially increased and maintained at an abnormally high level of density; whereas if an exotic fish can be acclimatised, it will proliferate and maintain its numbers to an extraordinary degree'.

Gambusia affinis appears to be capable of adapting itself to the climatic conditions prevailing in all parts of India where it has been tried, and it seems probable that it will prove capable of surviving in most parts of this country where malaria is a problem.

NOTES ON REARING *GAMBUSIA AFFINIS* UNDER INDIAN CONDITIONS.

(I) THE HATCHERY TANKS AT KARNAL

Eleven specimens of *Gambusia affinis* were received at Karnal in December 1929. Some of these were kept for the remainder of the winter in a small indoor aquarium, and some in a large earthenware container placed out of doors. Various aquatic plants were introduced into the containers and mosquito larvæ, when procurable, were supplied as food. In May 1930 a small cement concrete tank (5 × 5 × 2 feet) was stocked with 120 fish from the earthenware container. The number of fish in this tank increased very rapidly, and, in 1932, a larger tank (20 × 15 × 2 feet) was installed. Although only 100 fish were placed in the latter in the first instance, there were many thousands present in it within a few months. A third hatchery tank was installed at the Karnal Experimental Station in 1933. From these tanks very large numbers of *Gambusia* have been supplied to workers in various parts of India. The losses of fish incurred in this way are quickly made good during the breeding season (May to October in the Punjab). Where the food supply is adequate very large numbers of *Gambusia* can be maintained in a small tank (*vide* Plate VIII, fig. 1).

Gambusia affinis is a viviparous species, and experiments have shown that a single female may produce as many as 95 young in a single brood. Fresh broods may appear every month or six weeks during the breeding season.

(II) THE MAINTENANCE OF HATCHERY TANKS FOR *GAMBUSIA* IN INDIA.

The following notes on the procedure adopted for the rearing of *Gambusia affinis,* under Indian conditions, may be helpful to other workers who contemplate the installation of hatchery tanks for their own use. Under the conditions to be described it has been found that *Gambusia* maintain themselves well and multiply rapidly.

(*a*) THE TANK.

For ordinary purposes two or three small tanks (say, $10 \times 10 \times 2$ feet) should be sufficient to form a nucleus from which to stock mosquito-breeding places (suitable for fish) in a large area such as a town or a district. Such tanks should be constructed of brick and lined with cement concrete. The tank should be situated in such a way as to be partially shaded from the sun. If a piped water-supply be available this should be installed, otherwise hand filling will be necessary to make good any loss of water from evaporation, etc. It is convenient to construct the tank above ground level and to insert an outlet pipe through which the tank may be drained if this be found necessary or desirable. Our practice has been simply to replace water lost by evaporation, and it has not been found necessary in the six years since this work was commenced to drain any of the tanks. During the monsoon season there is a danger of the tanks overflowing with the consequent loss of fish, but this can easily be obviated by installing a suitable overflow pipe the inner end of which should be protected with a perforated metal disc to prevent the escape of small fish. A short piece of rubber hose-pipe may be used temporarily to remove excess water by siphonage.

(*b*) FOOD SUPPLY, SHELTER, ETC., FOR THE FISH.

It has been the practice in Karnal to introduce a variety of aquatic plants into the fish tanks. The tall waterweed (bulrush), *Sagittaria,* may be conveniently planted in one corner of the tank and offers excellent protection for the small fry. Another common Indian aquatic plant, *Ancharis,* besides being an excellent oxygenator, provides shelter for the young fish. *Spirogyra* and other algal plants should also be introduced. It may be necessary to supply a certain amount of mud from some neighbouring pond to afford suitable soil for these plants to take root. As soon as a variety of aquatic plants has become established, the fish should not want for a supply of natural food as various aquatic insects will soon commence to appear. Until this state of affairs has become established it is advisable to supply food for the fish such as the larvæ and pupæ of mosquitoes and other aquatic insects. Earthworms, chopped blood-clot and parched rice have also proved to be suitable foods but should be sparingly used, especially in small tanks, as they tend to foul the water. Once the tanks have become established daily feeding is unnecessary, but it has been our custom to ensure an abundant food supply during the breeding season. It will usually be found necessary to remove large quantities of aquatic vegetation periodically as overexuberant growth hinders the inspection and capture of fish and might even enable mosquito larvæ to escape the fish.

Although certain types of vegetation may afford considerable protection to the small fry, it may be found convenient to screen off one corner of the

hatchery tank with a movable wire gauze panel, the mesh of which will admit the young fish but exclude the larger ones which are liable to prey on them.

(*c*) Exclusion of predatory fish.

Much trouble may be experienced if the small fry or spawn of fish, which, when larger, prey on *Gambusia,* are introduced into the tanks. For this reason it is inadvisable to attempt to rear local fish in the same hatchery tank which is used for *Gambusia,* for in doing so there is a great danger of introducing the young of predaceous fish.

The 'murrhal' (*Ophiocephalus*) so commonly found in ponds, etc., in India is a menace in this way. When introducing various aquatic plants, weeds, mud, etc., into the hatchery tanks there is a danger of including the small fry of this or other predatory species at the same time. Even one or two of these predatory species of fish, when they increase in size, may, in the confines of a small tank, prey on the *Gambusia* to such an extent as to reduce their number very greatly, or even exterminate them altogether. An unfortunate experience of this kind led to much trouble in one of our tanks at Karnal. The removal of these larger fish is often a very difficult undertaking, and it may even be necessary to drain the tank to effect their capture.

(*d*) Water temperature in the hatchery tanks.

In the Punjab, the temperature of the water in small concrete tanks, especially when they are fully exposed to the direct rays of the sun, is subject to very considerable variations throughout the year. Records of the water temperatures in the largest of the hatchery tanks (20 × 15 × 2 feet) at the Experimental Station, Karnal, were kept for a complete year, and are given below :—

Month.	Year.	Maximum water temperature.	Minimum water temperature.
April ..	1933	86°F.	60°F.
May ..	1933	92°F.	74°F.
June ..	1933	90°F.	81°F.
July ..	1933	91°F.	81°F.
August ..	1933	88°F.	74°F.
September ..	1933	89°F.	78°F.
October ..	1933	86°F.	64°F.
November ..	1933	74°F.	52°F.
December ..	1933	55°F.	47°F.
January ..	1934	56°F.	38°F.
February ..	1934	64°F.	40°F.
March ..	1934	75°F.	54°F.

It will be observed from these records that the maximum water temperature occurred in May (92°F.), and the minimum in January (38°F.). *Gambusia affinis* flourished within this range of water temperature, and no season appeared to be inimical to their survival, although the fish are less active during the cold season. Breeding commences in April and continues throughout the warm summer months, but is in abeyance from October to

March. The range of water temperatures given above probably includes the maximum and minimum experienced in most parts of India where malaria is a problem. In certain places in the extreme north, particularly those at higher altitudes where frosts occur, it is doubtful whether *Gambusia* would survive the winter under natural conditions. In the United States of America it was found that *Gambusia affinis* could not survive the severe winter at Philadelphia, but the cold there is probably much more intense than in any part of India where malaria occurs.

(*e*) Overwintering of *Gambusia* in the laboratory.

Should it be found that *Gambusia* will not survive the winter in any malarious locality in India, it should be possible to carry them over the winter in indoor aquaria, and to re-stock hatchery tanks and mosquito-breeding places in the spring. Rapid proliferation should occur in the early part of the hot season and the fish should be well established before the commencement of the malaria season which in such places usually occurs from July to September.

In this connection it may be helpful to describe the procedure for keeping *Gambusia* through the winter in an indoor aquarium. A glass or other container of about 5 gallons' capacity is suitable and easily handled. In a single aquarium of this capacity not more than about six fish should be kept. Clean water should be used, and it is advisable to change it every 2 or 3 days. A small quantity of aquatic vegetation should be provided. Food should consist, as far as possible, of the larvæ of mosquitoes and other aquatic insects, but these may be difficult to obtain during the winter. Small quantities of earthworms, chopped blood-clot or parched rice may be given, but, as these, in common with meat, bread and starchy foods, tend to foul the water, it is advisable to supply them shortly before the water is due to be changed. The aquarium should be exposed to the sun for 2 or 3 hours every day, and the temperature should not be allowed to fall below 40°F.

If, for any reason, it is desired to keep *Gambusia* in a small indoor aquarium during the hot season, young broods should be removed. The water temperature should not be allowed to rise above 80°F. The addition of a little ice during the daytime will often help to obviate this.

TRANSPORTATION OF *GAMBUSIA AFFINIS* IN INDIA.

Since the breeding of *Gambusia* was commenced at Karnal in 1930, numerous requests have been received for supplies of these fish for anti-malaria work in many parts of India. Compliance with these requests has raised the question of a suitable means of transportation of the fish, often over long distances and under very trying climatic and other conditions. Formerly it was the practice to send the fish in large containers under the care of a special attendant whose duty it was to change the water and feed the fish at regular short intervals. This procedure was inconvenient and costly, and the results obtained were often unsatisfactory. For this reason attempts were made to devise an apparatus in which small numbers of live *Gambusia* could be despatched by passenger train, unaccompanied by a special attendant. The earlier attempts in this direction, which included a device for the automatic oxygenation of the water *en route*, met with only mediocre

success, but eventually a simple and satisfactory apparatus was devised by one of us (S. A. M.) and is described below.

DESCRIPTION OF THE FISH TRANSPORTATION APPARATUS USED AT KARNAL.

This simple and inexpensive apparatus for the transportation of small numbers of live *Gambusia* has been used extensively during the past two years, and has given very satisfactory results.

The apparatus is composed of (1) a glass container for the fish, and (2) a specially constructed wooden box in which the glass container is packed.

(1) It has been found that a suitable glass container is furnished by the ordinary four-pound sweet-jar which can be obtained locally in almost any bazaar (height 8 inches; diameter of body 5 inches; diameter of mouth 3 inches). The mouth is provided with a tightly-fitting rubber stopper which is pierced at its centre by a piece of glass tubing (3/10 inch bore) to admit air. The tubing is adjusted so that the inner end is flush with the inner surface of the stopper, while the outer end projects about 1½ inches beyond its outer surface. A piece of cotton gauze is tied over the external opening of the glass tube. It is convenient to paste a strip of paper along the outer surface of the jar on which the capacity of the jar may be graduated in pounds and ounces (*vide* Plate VIII, fig. 2).

(2) The special packing case consists of a rectangular box constructed of stout wood and having the following internal dimensions—length 12 inches; breadth 6 inches; height 7 inches. This box is fitted internally with supports for the glass container, which ensure that it is firmly held in position. At one end of the box a block of wood is inserted which is excavated in such a way as to receive the bottom of the glass jar. A stout wooden partition is inserted about 3 inches from the opposite end of the box, one half of which is secured to the bottom and the sides of the box, and the other half is attached to the under surface of the lid in such a way that when the box is closed the two halves of the partition are approximated. From each half of this partition a semicircular notch is cut so that when the lid is closed a spherical opening in the partition is formed which provides a rigid collar for the neck of the glass container. When the latter is in position the box is divided into two compartments the larger of which contains the body of the fish jar, and the smaller one the stopper with its projecting glass tube. In order to ensure free ventilation holes are bored in the top and the sides of the smaller compartment. The lid, which is hinged at one end, is provided with a metal handle, and when closed, is fastened with screw-nails. It is an advantage to ensure that the box is kept in the upright position and that it cannot readily be toppled over in transit. This is effected by affixing wooden extensions at the bottom corners which project about 6 inches laterally, and from the ends of which wooden stays are carried to the top corners (*vide* Plate VIII, fig. 3).

An apparatus constructed as described above has been extensively used for sending out small numbers of live *Gambusia* by passenger train in India on very numerous occasions, and, in spite of the rough handling which it must have received *en route*, no breakages have so far been encountered.

PLATE VIII.

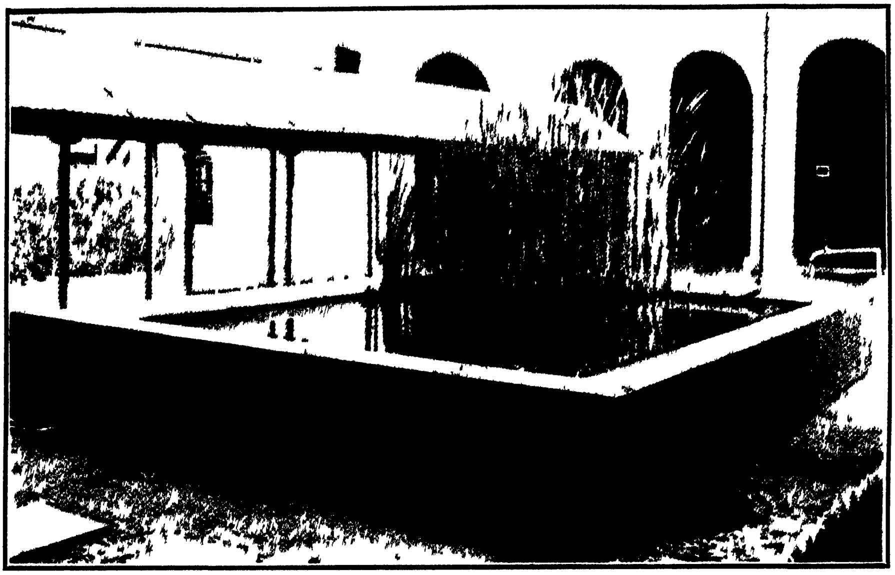
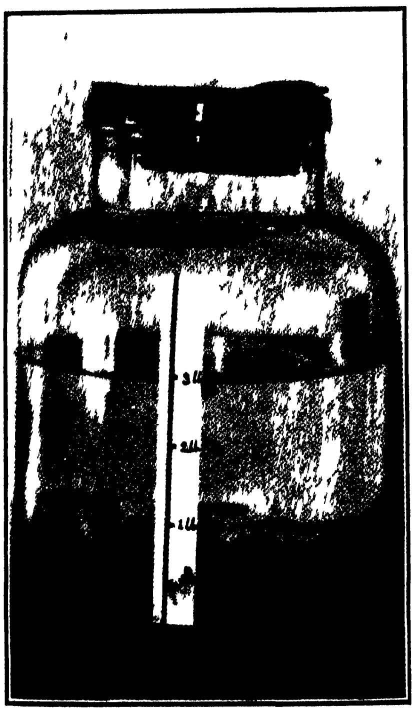
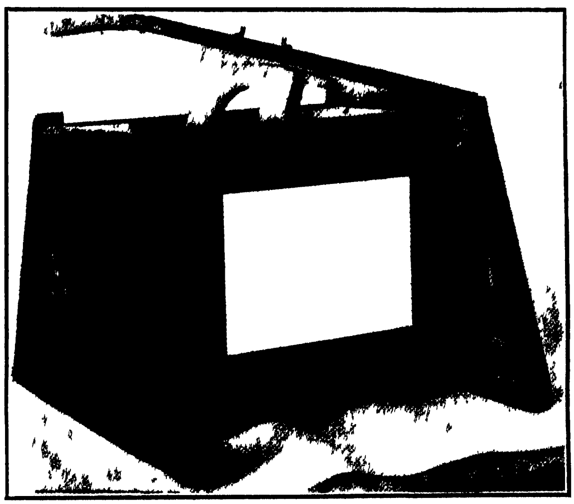


Fig 1—Fish hatchery tank at Karnal





Fish transportation apparatus.

Fig 2—Glass container

Fig 3.—Packing case.

In preparation for the despatch of a batch of fish, the glass jar is filled with clean water up to the 3 lb. mark, and a few small pieces of some aquatic plants are added. Not more than a dozen fish should be sent out in one consignment. Strong, healthy fish should be selected, and care should be taken to ensure that at least two male fish* are included, and that the fish receive no injury in transferring them from the hatchery tank to the jar. About 200 mosquito larvæ should be provided as food for the journey. The stopper should be fitted tightly and sealed with paraffin wax. In the hot season chilling of the water in the jar by placing it in the cold chamber or by adding crushed ice will help to ensure successful transportation. When placed in its special packing case, the long axis of the jar should form an angle of about 10° with the bottom of the box, thus ensuring a larger area of water surface for aeration. In this position the level of the water in the jar will be below the level of the inner end of the ventilation tube. Cotton-wool should be placed at all pressure points and a little may also be placed in the smaller compartment to absorb any small amounts of water which may escape through the ventilation tube. Leakage of water through this tube is negligible.

SUMMARY OF RESULTS OBTAINED WITH THE TRANSPORTATION APPARATUS.

With each consignment of fish, it has been our practice to enclose a *proforma* stating :—

(*a*) the number of fish sent out,
(*b*) the date and time of despatch,
(*c*) the amount of water in the glass container, and
(*d*) the temperature of the water at the time of despatch.

Blank columns are left on each *proforma* and the recipient is asked to fill in the details regarding the number of fish received alive, the amount of water in the jar, the date and time of receipt, etc. We wish to express our indebtedness to all those who have kindly furnished this information, from which it has been possible to compile extensive records of the success, or otherwise, of our transportation experiments. It is not possible here to analyse in detail the results which have been obtained, but we can state with confidence that, with the apparatus described above, the results have been uniformly excellent. A few examples may be quoted.

In August 1935, twenty-four *Gambusia* were despatched in two containers to Vizagapatam. The distance covered was 1,923 miles in 7 days, and all fish were received alive. A batch of twelve *Gambusia* was despatched to Bhatapara, a distance of 1,452 miles from Karnal, in September 1935, and all were received alive after a journey lasting for 5 days. In December, a batch of 15 fish were sent to Calcutta, a journey of nearly 1,000 miles. All were received alive although the fish remained in the apparatus for eight days. Numerous other examples of long railway journeys lasting from one to four days could be quoted in which all the fish survived. In June 1934, twenty *Gambusia* were kept in the laboratory packed as for transport. All remained

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* Male fish are easily recognised by the greatly elongated anal fin.

alive for two days although the water temperature was about 95°F. There was, however, a high mortality on the third day. A similar experiment conducted in January 1934 showed that eight out of ten fish remained alive for 43 days, but only one was alive on the 64th day. The water temperature in this instance was about 52°F.

No difficulties should be experienced in transporting larger numbers of fish over localised areas. Various methods for doing this have been described in the literature but need not be considered here. Any sizable container, such as an empty kerosene tin, should be easily adaptable and should prove satisfactory.

THE USE OF FISH IN ANTI-LARVAL WORK IN INDIA.

It cannot be claimed that the use of *Gambusia*, or any other larvicidal fish, has proved, or is likely to prove, to be the solution of the malaria problem in India. On the contrary all that can be said is that larvicidal fish may be a useful *adjuvant* to other measures of mosquito control under a variety of conditions, and may be a satisfactory solution of the problem in certain very limited circumstances. Very many of the most dangerous mosquito-breeding places in India cannot be effectively controlled by fish either (1) because suitable fish will not survive in sufficient numbers, or (2) because the nature of these breeding-places is such that the larvæ are able to escape their natural enemies.

Several factors may be operative in reducing the number of *Gambusia* in a given breeding-place or even in causing their extermination. The presence of larger predatory fish may be an important factor in the reduction of the numbers of larvicidal fish to a level which is insufficient to control mosquito-breeding. The absence of an adequate food supply will also tend to limit the number of fish some of which, such as *Gambusia*, become cannibalistic in such circumstances. The chances of mosquito larvæ escaping the attentions of the fish in such places would be remote owing to the scarcity of alternative food, but in the case of *Gambusia* cannibalism would probably lead to a reduction in their numbers, or at least to an inhibition of their proliferation, and periodical re-stocking would be necessary. Another factor tending to the reduction or extermination of fish is the temptation to small boys or other persons to remove them, a drawback which is difficult to control. Pollution of the water to an extent which would be unsuitable for the survival of *Gambusia* would, if permanent and continuous, almost certainly render the water unsuitable for the breeding of dangerous anopheline mosquitoes. Another difficulty in the maintenance of *Gambusia* or other fish is the liability of breeding-places to become completely dry during periods of drought, or as the result of periodical draining of tanks and reservoirs. In the latter instance this difficulty may sometimes be overcome by providing small deep pools or excavations in which the fish can survive the period during which the major portion of the tank or reservoir is empty.

In many breeding-places for dangerous mosquitoes the conditions are such as to enable the larvæ to escape the fish, and the latter may therefore be ineffectual in controlling mosquito-breeding. Among the factors which favour the survival of larvæ, even when apparently adequate numbers of fish are present, are the presence of excessive vegetation, shallow and overgrown

edges, and an abundance of floating debris, etc. By the periodical removal of excessive vegetation, floating debris, and the provision of steep clean-cut edges mosquito-breeding may often be greatly diminished if suitable fish are present in adequate numbers. This procedure, however, adds greatly to the expense of the undertaking, and in many instances it would be found cheaper and less troublesome to employ some other means of larval control.

When using fish as an adjuvant to other measures of control, it should be remembered that oil and some chemical larvicides may be highly toxic to fish. Paris green is, however, innocuous to *Gambusia* or any other species of fish, at least in the amounts employed for antimalarial work.

TYPES OF MOSQUITO-BREEDING PLACES IN INDIA WHERE *GAMBUSIA* HAVE BEEN FOUND TO BE MOST USEFUL.

Perhaps the greatest benefit from the use of fish in mosquito-breeding places in India is derived in places where other methods of control are either contra-indicated or prohibited. In some such places the use of fish may be an entirely satisfactory solution of the problem, while in others their use may be regarded merely as the best that can be done in the circumstances. The control of mosquito-breeding by such measures as oil, paris green or other chemical larvicides may be contra-indicated, or objected to, in a variety of circumstances, particularly in regard to water used for domestic, ornamental or religious purposes. Other methods, such as periodical drying or mosquito-proofing, may also be impracticable or subject to objection. Such places include wells, tanks, ornamental waters, etc., particularly those of religious significance, and fish have often proved of great value in places of this kind. Not only may the use of fish be permitted in such places, but the conditions are often such as to allow them to control mosquito-breeding cheaply and effectively.

Gambusia may also prove of value in reservoirs or other impounded waters, especially those in which there is little or no floatage or vegetation, and where the edges are steep and clean-cut. In places of this kind it is often possible to enhance the value of fish by raising and lowering the water level periodically thereby ensuring a cleaner margin, the destruction of algal growths and the washing out of larvæ from the edges so that they are more accessible to the fish.

In addition to the types of breeding-places mentioned above where, for various reasons, the use of larvicidal fish may be the only practicable anti-larval measure, or where their use, either alone or combined with other measures, is a satisfactory solution of the problem, there are many other conditions under which the use of fish may be combined with other methods. In referring to these it must be emphasised that, in many instances, the use of fish can only be regarded as a supplementary measure, and that grave danger may arise from placing too much reliance upon them. Unless their use be definitely precluded by the employment of oil or other noxious larvicides, there is no objection to supplementing other measures of malaria control with fish, nor is there any objection to giving fish a trial in breeding-places of many kinds, whether in fresh or brackish water, where other measures are impracticable for financial reasons, on the principle that some control is better than none. There is here a danger, however, that the unenthusiastic sanitarian may consider his duties discharged when he has placed a few fish in certain breeding-places, and may thereafter live in a fool's paradise.

SOME PRECAUTIONS TO BE EXERCISED IN THE USE OF *GAMBUSIA* IN MALARIA CONTROL.

1. Stocking and re-stocking of breeding-places.

The number of fish to be introduced will depend on the size of the breeding-place, and upon whether the fish are intended as a nucleus from which to breed, or to obtain immediate results. For wells and small tanks, a half to one dozen fish should be sufficient to form a nucleus, but for larger places several hundreds may be supplied. Care should be taken to see that a proportion of male fish are included, one or two males in every dozen being sufficient. If the food supply be insufficient *Gambusia* will eat their own young, and it will be found necessary to re-stock periodically.

2. Supervision and inspection.

One of the chief disadvantages in the use of fish for antimalaria work is the necessity for frequent inspection. This is necessary to ensure that fish are present in sufficient numbers, that they are actually controlling mosquito-breeding, and, if not, that the cause of their failure to do so is removed, or other measures substituted. It may be necessary to employ a special staff to carry out these inspections, to maintain a supply of fish from which to stock various breeding-places, and to re-stock them as occasion arises. In the case of wells and other similar places where inspection is difficult and time-consuming, the best procedure is to re-stock periodically as a routine measure. It has been found that in the wells of certain cities in India *Gambusia* will usually survive for at least eight months even in deep wells where there is very little food. In such circumstances the routine practice should be to place about six fish in each well every six months, the re-stocking being commenced on specified dates such as 1st January and 1st June of each year.

3. Elimination of predatory fish.

The importance of excluding predatory fish from hatchery tanks has already been emphasised. This precaution may not be feasible in large breeding-areas such as lakes and reservoirs, nor is it of importance. It is, however, of great importance in the case of small and confined breeding-places where the presence of even a single large fish may eliminate all the *Gambusia* in a very short time.

4. Provision of fish sanctuaries.

It sometimes happens that mosquito-breeding places which are amenable to control by fish have to be drained or become dried out. In such cases it is necessary to provide fish sanctuaries in which the fish may be able to survive the period of drought. The methods of doing this have already been described.

5. Removal of vegetation and floatage.

It has been our experience that *Gambusia* may be completely effective in controlling mosquito-breeding even in the presence of considerable amounts of vertical and horizontal vegetation. Horizontal vegetation or floatage may, however, give considerable protection to the larvæ, and its removal may be

so costly and troublesome as to indicate some other method of larval control. Some measures for reducing the amount of floatage and horizontal vegetation have already been mentioned.

In view of these considerations it will be realised that the use of *Gambusia*, or other larvicidal fish, is not simply a matter of putting in some fish and then assuming that the problem of larval control is solved. There are many and serious disadvantages to their use, but they have a definite value in malaria control work, particularly in circumstances where other measures are contra-indicated or prohibited.

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SOME EXPERIMENTS WITH 'ENTORAY' MACHINE AS AN ANTI-MOSQUITO MEASURE.

BY

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[25th May, 1936.]

WITH the great development of shipping and air traffic the possibility of the introduction of Yellow Fever into India has been freely discussed for some time past. It therefore appeared desirable to test the value of the 'Entoray' machine as an anti-mosquito measure in a docks area, as it was suggested that several of these machines might be introduced if their value could be established. Mr. V. Menasché, Managing Partner of the Societe Nomosquito, the firm responsible for the manufacture and sale of 'Entoray' machines, was agreeable to this and kindly placed an 'Entoray' apparatus at our disposal to carry out experiments and to test for ourselves the utility of the machine in a docks area before recommending its installation.

The machine consists of a mercury vapour lamp emitting a bluish light placed at the top of a hollow square pillar, down which a column of air is sucked by a powerful motor fan placed in the base of the machine—the air passing through a wire gauze box in which all the insects attracted by the machine are trapped. The idea which this machine embodies is an attractive one—a ray luring mosquitoes to their destruction—especially as the anti-mosquito measures already in use are expensive, and under conditions appertaining in a docks area cannot guarantee cent per cent elimination of all insects imported by shipping.

The experiments described below were carried out between 27th September, 1935 and 1st November, 1935.

The machine was installed at the Red Gate, Alexandra Docks, of the Bombay Port Trust. Throughout the experiments full meteorological records

were kept, windage being recorded at ground level, when possible, and at other times records were taken from the Bombay Port Trust station at 140 feet above ground level from which the ground level conditions can be estimated.

EXPERIMENT I.

PRELIMINARY EXPERIMENT.

A preliminary experiment was carried out on 27th September to ascertain whether marked mosquitoes released up, down, or across wind at a given distance were attracted by the machine, and, if so, within what period of time. To this end about 1,350 culicine mosquitoes were divided into 3 batches in cotton-net cages and were respectively stained red with eosin, orange with orange G, and blue with brilliant blue.

Two per cent aqueous solutions of eosin, orange G and brilliant blue were sprayed onto different batches of mosquitoes with a Devilbiss No. 15 spray. Spraying was done gently and continuously to avoid injuring or overloading mosquitoes with the stain. Mosquitoes were always sprayed 8 to 10 hours before they were required, to make sure that they were not in any way injured and had fully recovered from the effect of spraying before they were actually used for an experiment.

Presence of stain on a mosquito in any given catch was detected by dipping individual mosquitoes in small quantities of a solvent consisting of glycerine 1 part, methyl alcohol 1 part, and chloroform 1 part. Batches of mosquitoes stained with 2 per cent aqueous solutions of these dyes, when examined from day to day for a whole week in the laboratory for the presence of stain, showed that the stain could easily be detected on mosquitoes during this period.

At 7-15 p.m. on 27th September the stained mosquitoes were released at the same moment at 250 yards' range from the machine which had just been turned on, the red being released to fly down wind towards the machine, the orange to fly across, and the blue to fly up against the wind. The wind at ground level was at the rate of 1·8 m.p.h. as recorded by a portable anemometer placed on the top of a car.

After the first half-hour timed from the commencement of the experiment the gauze box in the machine was taken out and another substituted. Later, it was found that 8 mosquitoes (5 anopheline and 3 culicine) had been caught but none of them was of the stained batches.

At the end of the second half-hour only 1 more anopheline had been caught. During this period the ground wind was 2·5 m.p.h.

Thereafter the machine was run for a full hour, the wind being 1·2 m.p.h., and it was later ascertained that in this period 7 mosquitoes (5 anopheline, 1 culicine stained with orange, and 1 unidentified) had entered the 'Entoray' machine.

It was then decided to run the machine all night until 6 a.m. on 28th September, 1935, during which period the official windage was 10·5 m.p.h. from the N.W., the temperature dropped to 78°, the mean humidity was 79 (maximum 84, minimum 73), and 58 anopheline mosquitoes were caught but no further trace of the stained ones was seen.

In this case only one stained mosquito travelled across the wind to the machine, which suggests that the latter has little attraction for culicine or *Aëdes* mosquitoes at a range of 250 yards close to the sea and at sea level.

EXPERIMENT II.

SHORT-RANGE RELEASE.

On 1st October a short-range release of about 200 blue-stained culicine mosquitoes was tried at 10 yards from the machine, official windage being 10·25 m.p.h., ground rate 2 m.p.h. from the N.W., temperature between 80° and 79°—and mean humidity 81 (varying from 84 and 77).

Starting the experiment at 8 p.m., 6 (1 anopheline and 5 culicine) mosquitoes were caught during the first half-hour and thereafter the machine was allowed to run till 6 a.m. on 2nd October, 1935, during which time 42 (17 anopheline and 25 unidentified) mosquitoes were trapped. At the commencement of this experiment at 8 p.m. one or two mosquitoes on release were seen to fly straight for the lamp but the rest circled up, round and away. From this one must infer that even at 10 yards the lamp exerts little attraction for mosquitoes under conditions obtainable in a docks area.

EXPERIMENT III.

RESIDUAL COLLECTION.

On the following night the machine was run from 8 p.m. until 6 a.m. next morning to see whether any stained mosquitoes had taken shelter in the vicinity and might be caught on recovery from the effects of staining, if any. On this occasion the official wind rate at 140 feet above ground level started at 13·5 and dropped to 9·5 m.p.h. coming from the N.N.W.-N., the wind at ground level in the vicinity being estimated at about 2 m.p.h. as before. The temperature started at 82°, falling to 80° through the night, and the mean humidity was 83, varying between 86 and 79. On this occasion 64 mosquitoes were caught, of which 22 were anopheline and 42 unidentified. None of these however proved to be stained though the average catch of between 50 to 70 per night was maintained.

EXPERIMENT IV.

EFFECTS OF STAINING ON POWERS OF FLIGHT.

A suggestion having been made that staining might interfere with the flying powers of mosquitoes, on 8th October a control experiment was carried out under much the same climatic conditions, 200 unstained culicine mosquitoes being released from the same spot at 10 yards' distance from the machine.

Unfortunately the machine had to be stopped after half an hour as one of the fan-blades appeared to be touching the side, but during that period 3 mosquitoes (1 *Anopheles*, 1 *Culex*, and 1 *Aëdes*) were caught. This was the only occasion throughout all the experiments on which an *Aëdes* mosquito was caught, which suggests either that this variety of mosquitoes is scarce in the docks or that the lamp has little attraction for the genus. Scarcity of *Aëdes* is difficult to believe in view of the close proximity of tenement buildings, etc., in the municipal area near the scene of our experiments. These results are comparable with those obtained in Experiment II and would seem to suggest that staining of mosquitoes in no way interferes with their flight.

EXPERIMENT V.

'ENTORAY' LAMP ATTRACTION.

In order to ascertain how many mosquitoes were caught by accidently flying within the suction radius of the machine as compared with those definitely attracted by the light itself, the machine was run for a whole night (10 hours) on 10th October without turning on the lamp at all, and only 7 mosquitoes (2 anopheline and 5 culicine) were caught.

Climatic conditions in this case were much the same as in other experiments.

EXPERIMENT VI.

EFFECTS OF LIGHT OTHER THAN THAT OF THE 'ENTORAY' LAMP.

This experiment was repeated on 15th October using a plain white 600 watt lamp, and over the same period and under the same conditions an almost identical catch was made as during the previous experiment, viz., 8 mosquitoes (2 anopheline and 6 culicine), which constituted the largest number of identified culicines caught in any one night. This suggests that the 'Entoray' lamp does exert some degree of attraction for anopheline mosquitoes. Conversely we are informed that in other parts of India the maximum effect appeared to be upon culicine and *Aëdes* mosquitoes but we have seen no written reports to this effect. As to whether such variation in results is accidental or depends upon such factors as the relative preponderance of any particular genus, the saline content of the atmosphere in the docks area, etc., we are unable to express any opinion.

EXPERIMENT VII.

EFFECTS OF 'ENTORAY' LAMP ON UNSTAINED ANOPHELINE MOSQUITOES.

To avoid any possibility of infecting the docks with malaria, etc., by the release of possibly infected anopheline mosquitoes, special consignments of species of non-carrier mosquitoes were obtained from Karnal through Malaria Survey of India, of which about 300 were on the night of 1st November released to windward at about 10 yards. A few went straight towards the lamp on release, and on this particular night numerous insects were seen entering the suction ring. The catch in this case was almost up to average, 42 mosquitoes, representing 19 anopheline, 2 culicine, and 21 unidentified. Further experiments with this genus of mosquitoes were thenceforth stopped as the proportion of those recovered was too small to justify the risks involved in further release.

OTHER EXPERIMENTS.

Three further experiments were conducted to verify the reported lethal effect of the actual rays upon mosquitoes, but owing to a change in the climatic conditions, and to certain defects noted in the matter of the control experiments resulting in possible vitiation of conclusions, no details regarding these experiments have been included in this report.

INSECTS OTHER THAN MOSQUITOES CAUGHT BY THE 'ENTORAY' MACHINE.

The insects from one catch were sent for identification to Mr. S. H. Prater of the Natural History Society, to whom our thanks are due. Besides the

mosquitoes in each catch there were numerous moths, beetles and dragonflies. The greatest part of the collection consisted of 'beneficial' insects such as ichneumon wasps and others; there were also some harmless beetles and acalyptrate flies. The night catches of these insects were counted on two different occasions and were 3,000 and 5,000 in number.

The following list shows the classification of the identifiable insects trapped by the machine :—

1.	Moths—Noctuidæ, etc.	163
2.	Beetles—Coleoptera (Carabids, Dytiscids, etc.)	72
3.	Grasshoppers including 3 Catidids (Orthoptera)	7
4.	Crickets—Gryllidæ (Orthoptera) ..	9
5.	Stick insects including 1 Mantis (Phasmidæ)	9
6.	Bugs—Hemiptera	14
7.	Earwigs—Forficulidæ	1
8.	Midges—Chironomidæ, etc.	23
9.	Bluebottle flies—Muscidæ	23
10.	Flies—Diptera	24
11.	Aphids—Fulgoridæ (Homoptera) ..	28
12.	Fruit flies—Diptera (Drosophila) ..	22
13.	Ichneumon flies—Hymenoptera (Ichneumonidæ)	19

SUMMARY AND CONCLUSIONS.

Known numbers of culicine and anopheline mosquitoes were released in close proximity to the machine, in some cases as near as 10 yards, and the machine run for a whole night (10 hours) after each release. Out of the 1,550 stained culicine mosquitoes released, the machine caught only one during a working period of 3 nights (30 hours). During this period 185 unstained mosquitoes, however, were trapped by the machine out of the local fauna. Though no attempt was made to ascertain precisely the local population of mosquitoes, the number caught seems to be insignificant. When 300 anophelines were released near the machine, it caught 19 during a working period of about 10 hours. It is not possible to say how many of these were from the local fauna, as the mosquitoes released were not stained. In addition, during a working period of 20 hours, the first two days of the experiment, about 8,000 other insects (mostly 'beneficial') were caught by the machine.

These results show that the machine tested is not a practical anti-mosquito measure under the conditions of the above experiments; but, as already stated, the principle of the machine is attractive so that further research might be worth while to ascertain whether any ray can be discovered which will unfailingly bring mosquitoes within the suction radius of the machine.

ACKNOWLEDGMENTS.

We desire to record our thanks to Mr. V. Menasché for the supply of the machine, to Lieut.-Col. J A. Sinton, V.C., O.B.E., M.D., D.SC., D.P.H., D.T.M., I.M.S., Director, Malaria Survey of India, Kasauli, to Dr. J. S. Nerurker, B.SC., L.M.S., D.P.H., Executive Health Officer, Bombay Municipality, for the supply of mosquitoes, and to the Bombay Port Trust authorities for all their assistance and interest in the investigations.

1	2	3	4	5	6	7	8		
Number of experiment.	Nature of experiment.	Date.	Windage m.p.h., B.P.T. at 140 feet.	Windage ground level.	Wind direction from	Temperature.	Humidity, per cent.		
							Mean.	High.	Low.
I	Preliminary with stained culicine:— (*a*) Red. (*b*) Orange. (*c*) Blue.	27-9-35	10·5	1·8 2·5 1·2	N.W.	82° 82° to 79°	79	84	73
II	Short-range release of blue-stained culicine mosquitoes.	1-10-35	10·25	2·0	N.W.	80° to 79°	81	84	77
III	General and residual catch after Experiment II.	2-10-35	13·5—9·5	..	N.N.W. to N.	82° to 80°	83	86	79
IV	Control on II. Short-range release of unstained culicine mosquitoes.	8-10-35	13·5	3·5	N.N.E.	86°	82	84	80
V	Control on III *without lamp* to note effects of suction only.	10-10-35	15—8·75	..	N.N.W. to N.	86·5° to 81·5°	81	84	74
VI	Machine run *with plain white* 600 watt *lamp.*	15-10-35	11·5	..	N.	86° to 81°	70	80	61
VII	Special effect of *mercury vapour* lamp on unstained anopheline mosquitoes.	1-11-35	7 10—8	.. ..	W.S.W. N.E. (variable).	83° to 79° 80°	79	82	77

9	10	11	12	13	14	15				16
						VARIETIES.				
Number of mosquitoes released.	Time of start, p.m.	Direction from which released.	Distance of release from lamp.	Period of collection.	Number caught or recovered.	Anopheline.	Culicine.	*Aëdes.*	Unidentified.	REMARKS.
450 of each colour = 1,350.	7·15	N.W. N.E. S.E.	250 yds.	1st ¼ hour 2nd ½ hour 3rd 1 hour 4th all night, 9-15 p.m. to 6 a.m., 28-9-35.	8 1 7 58	5 1 5 58	3 .. 1 ..	.. ..	.. .. 1 ..	One orange stained *Culex* caught from across wind.
200	8	N.N.W	10 yds.	1st ¼ hour 2nd all night, 8-30 p.m. to 6 a.m., 2-10-35.	6 42	1 17	5 ..	.. ..	.. 25	On release, one or two mosquitoes went straight for the lamp, but the rest circled round.
Nil	8	..	..	10 hours, 8 p.m. to 6 a.m., 3-10-35.	64	22	..	..	42	Average of other experiments appeared to be maintained
200	7·50	N.N.W	10 yds.	1st ¼ hour	3	1	1	1	..	On release half a dozen mosquitoes flew back towards electric torches, showing no attraction towards lamp. Machine stopped after ¼ hour, as noise developed in the motor, so not run overnight.
Nil	8	..	..	10 hours, 8 p.m. to 6 a.m., 11-10-35.	7	2	5	..	..	....
Nil	8	..	..	10 hours, 8 p.m. to 6 a.m., 16-10-35.	8	2	6	..	..	To ascertain whether a different coloured lamp would attract more mosquitoes than the mercury vapour lamp.
300	7·35	E.	10 yds.	1st ½ hour 2nd all night, 8-5 p.m. to 6 a.m. 2-11-35.	10 32	8 11	2 ..	.. ..	.. 21	Karnal mosquitoes used. Some went straight towards lamp on release. Numerous insects seen entering machine this night.

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A. MINIMUS IN ASSAM, ITS COLD WEATHER BIONOMICS AND THEIR RELATIONSHIP TO ANTI-LARVAL CONTROL*.

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INTRODUCTION.

In a previous paper (Rice, 1935*a*) it was stated that '*A. minimus* breeding continues actively throughout the cold weather months, and that the larvæ found in perennial streams do not remain in a stage of hibernation but emerge as adults'. Another statement in this paper read '........it is not considered that this (the) subject of transmission during the cold weather has been sufficiently studied, and it is suggested that, although the numbers of *A. minimus* found during this season of the year are comparatively small, transmission may still continue'.

As these conclusions were not in agreement with those previously recorded by other workers, it was considered not only desirable but necessary to institute further researches with the object of evolving, by researches, scientific fundamental principles upon which to base recommendations for a defined seasonal period at which to commence anti-larval activities directed specifically against *A. minimus*, the known vector species in Assam.

Other workers have regarded *A. minimus* adults, although present in the cold weather months, to be of no malariogenic significance at this time, as they have stated that they remain in a state of hibernation, their feeding stimulus is inactive and the sporogony cycle is not completed during that period of the year when night (minimum) temperatures are below 60°F. and, due to these factors, transmission does not take place. It has also been regarded by some workers that, in the larval stage, *A. minimus* passes through the cold weather in a state of wintering and, therefore, progeny do not emerge from

* Appendices referred to in this paper have been placed in the Library of the Malaria Survey of India, Kasauli, and are available on loan to workers who wish to consult these. (*Editor.*)

these wintering larvæ to be of malariogenic significance during the cold weather months. From these conclusions it has been generally advocated that anti-larval activities should not be applied before 15th March annually.

In this investigation the several researches considered necessary were started in November 1935 and were continued to the end of March 1936. The researches were carried out on a tea estate near Doom Dooma town in the northernmost and coldest part of the plains of Upper Assam where malaria is hyperendemic and the minimum temperatures recorded annually are consistently as low as, or often lower than, those experienced elsewhere in the plains of Assam.

This report presents those data and findings resulting from the several researches undertaken, together with our interpretation of the significance of the findings when considering the period at which scientific anti-larval control, directed against the known vector *A. minimus*, should be commenced annually in order to obtain the most efficacious and economical results as regards the reduction of the malaria case incidence in controlled areas.

During the investigation the total numbers of larvæ and adult anopheline specimens caught monthly are recorded in Tables I and II. The adult catches do not, however, include the *A. minimus* catches made, and subsequently recorded in this report under the Observation Station series.

TABLE I.

Larval catches.

November to March.

Species.	1935.		1936.			Total.
	November.	December.	January.	February.	March.	
A. aconitus ..	130	569	672	98	38	1,507
A. aitkeni var. *bengalensis.*	..	2	9	..	..	11
A. annularis ..	770	939	1,470	961	1,982	6,122
A. barbirostris ..	53	119	131	51	107	461
A. barbirostris var. *ahomi.*	..	23	38	40	..	101
A. culicifacies ..	3	..	2	..	2	7
A. gigas var. *baileyi.*	..	1	1	..	..	2
A. hyrcanus ..	280	859	884	657	503	3,183
A. insulæflorum	..	..	..	1	..	1
A. kochi ..	..	1	..	2	..	3
A. maculatus ..	5	28	265	256	245	799
A. minimus ..	841	662	908	1,177	932	4,520
A. pallidus ..	138	71	6	..	..	215
A. philippinensis	38	217	88	11	..	354
A. vagus ..	42	21	23	2	..	88
TOTAL ..	2,300	3,512	4,497	3,256	3,809	17,374
PERCENTAGE: *A. minimus.*	36·6	18·8	20·2	36·1	24·5	26·0

TABLE II.

Adult catches.

November to March.

Species.	1935. November.	1935. December.	1936. January	1936. February.	1936. March.	Total.
A. aconitus ..	39	54	8	13	5	119
A. annularis ..	79	113	94	60	118	464
A. fluviatilis ..	..	38	52	49	17	156
A. hyrcanus ..	1	24	16	12	4	57
A. lindesayi ..	1	..	..	..	..	1
A. maculatus ..	3	2	19	34	47	105
A. minimus ..	1,590	727	415	211	306	3,249
A. philippinensis	3	1	4	..	..	8
A. umbrosus ..	..	..	1	..	..	1
A. vagus ..	26	216	47	6	6	301
A. varuna ..	15	43	105	47	3	213
TOTAL ..	1,757	1,218	761	432	506	4,674
PERCENTAGE: *A. minimus*.	90·5	59·7	54·5	48 8	60 5	69 5

The meteorological data, including the daily minimum and maximum temperatures, and the relative humidity and rainfall, for the period of the investigation are given in the Graph*.

I. LARVAL INVESTIGATIONS AND OBSERVATIONS.

STREAM BREEDING EXPERIMENTS.

To confirm previous reports (Rice, 1935*a*, 1935*b*) that the developmental cycle of *A. minimus* continued uninterrupted in the plains districts of Assam throughout the cold weather months, breeding experiments were undertaken under conditions made as nearly natural as possible, and under the meteorological variations prevailing.

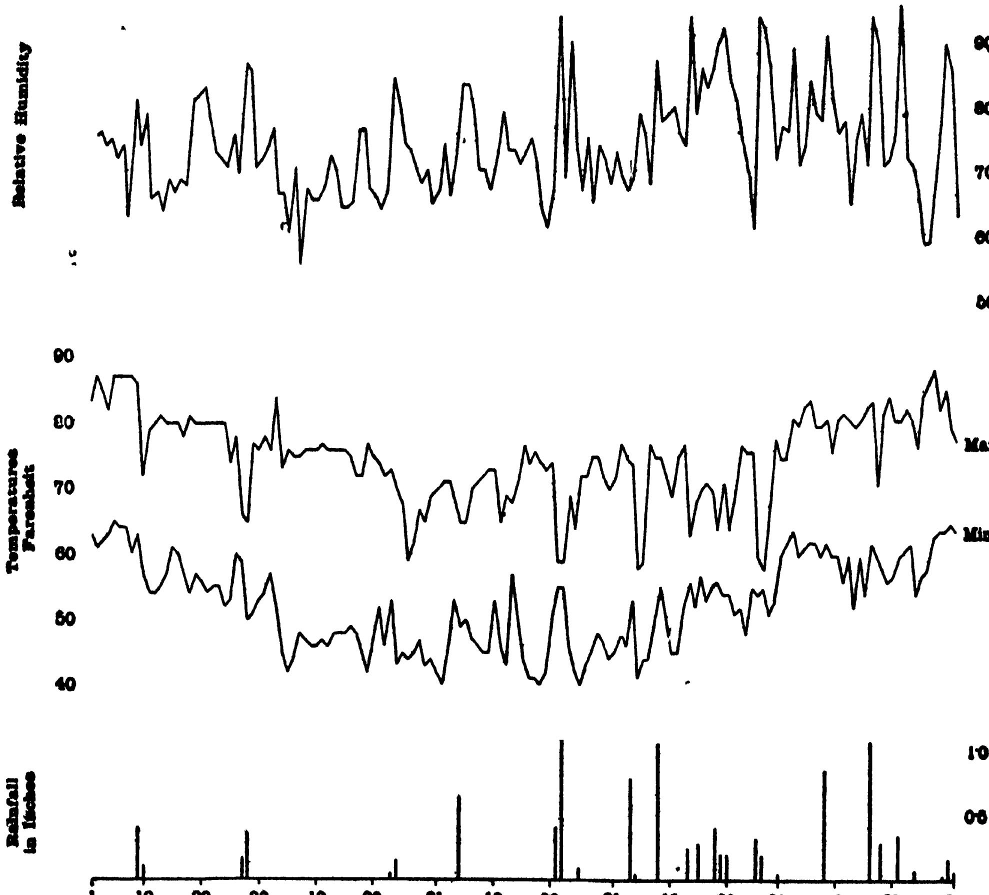
(*a*) METHODS USED IN STREAM BREEDING EXPERIMENTS.

1. Gravid *A. minimus* were isolated individually in 3×1 inch tubes, inside of which had been inserted, in a spiral manner, a $\frac{1}{2} \times 2$ inch strip of filter paper resting on the sides of the tube, but *not* touching the moistened cotton-wool plug. The filter paper was inserted to absorb any excess of moisture present, which might otherwise have fouled the wings of the insect. The open end of the tube was plugged with moistened cotton-wool over which had been placed, to cover the wool, a circular piece of filter paper on which eggs could be deposited. The tube was placed in a rack with the cotton plug downward. Many gravid females were isolated in this manner, whenever

* We are indebted to Mr. H. O. Swannell for recording the meteorological data.

GRAPH.

Meteorological data, 1935–36.



eggs were required. In each case it was noted that eggs were laid between 5 p.m. and 8 a.m. These are, as will be shown presently, *voluntary* ovipositions and, in every instance, the eggs were fertile.

2. A 12 × 12 × 12 inch wire frame was prepared to support a cage made with muslin sides (one side having a sleeve) and net top. This cage was fixed, exposed to direct sunlight and half submerged in a stream pocket by means of four stakes in such a manner that water could flow freely through the cage, but other larvæ and predaceous insects would be excluded. Through the sleeve, growing rooted grass was placed along the sides of the cage to represent the grassy condition of stream edges.

3. The eggs, after having been counted, were placed on the water inside the prepared cage by gently floating them from the filter paper on which they had been laid overnight..

4. Examinations were made from day to day to determine the time periods in the various immature stages, otherwise the cages were not disturbed until adults emerged and were caught therefrom.

Table III gives particulars of the five experiments made on breeding *A. minimus* in a stream, during different months of the cold weather season under the varying meteorological conditions present.

To observe whether there were any variations in the developmental cycle of *A. minimus* under differing water conditions, and as a control to the stream breeding experiments, parallel experiments in the open air were carried out during the same periods.

(*b*) Methods used in open air laboratory breeding experiments.

1. Same as stream breeding.

2. Enamel dishes, 9 inches in diameter and $2\frac{1}{2}$ inches deep, were lined with stream mud ($\frac{1}{4}$ inch thick on the sides and $\frac{3}{4}$ inch thick at the bottom) and rooted grass, which had been thoroughly washed, was then fixed to the sides and in the centre of the dish, so that the whole was made to simulate a swampy area. The dishes were then placed in the direct sun and dried out to preclude the possibility of predaceous forms being present. After thorough drying, water, taken from the same stream in which the stream breeding experiments were being carried out, was placed in the dish, after removing any larvæ or other insects.

3. Same as stream breeding.

4. Examinations were made to determine the time periods of the various immature stages as in the stream breeding experiment. The dishes were kept, day and night, in the open air and subjected to direct sunlight or partial shade by day. The water was changed every second day. With the first pupation in evidence, the dish was removed to an open air laboratory and placed within a breeding cage until all progeny had emerged.

Table IV gives the particulars of five open air laboratory breeding experiments carried out under similar meteorological conditions to the stream breeding experiments.

I. Rate of developmental cycle.

In reviewing Tables III and IV, it is seen that the egg and pupal stage periods closely approximate each other in both experiments. However, in the larval stages, up to the time of the first and last pupations, the average rate of development was of shorter duration in the dish breeding control when compared with the stream breeding experiment. This difference was more marked during the periods when the mean temperatures were low, but the time periods of development in these experiments tended to become more equable with the rising mean temperatures in March.

It appears probable that the more rapid development among those larvæ bred in dishes was due to relatively higher temperatures of the water as compared to the relatively lower temperatures of the natural stream water. Similarly, it is probable that under varying *natural* water conditions in the cold weather months, but with identical prevailing climatic factors, the larval span may vary considerably.

TABLE III.

Stream bred A. minimus.

	Period of experiment.	Date eggs deposited.	Number eggs deposited.	Period of immature stages in days.			Average developmental cycle period in days.	Resulting progeny.								Meteorological data.				
								Number.			Percentage.			Sex ratio.						
				Egg.	Larval.	Pupal.		Male.	Female.	Total.	Male.	Female.	Total.	Male.	Female.	Average maximum temperature.	Average minimum temperature.	Average mean temperature.	Average humidity.	Total rainfall in inches.
I	December	1st Dec.	99	4 to 6	20 to 30	4 to 5	34	16	14	30	16·2	14·1	30·3	53·3	46·7	74·2	47·9	61·0	68·7	0·19
II	January	26th Dec.	84	6 to 7	22 to 30	5 to 6	38	13	9	22	15 5	10 7	26·2	59·1	40·9	70·2	46·9	58·3	73·4	2·26
III	February	23rd Jan.	93	5 to 7	19 to 22	3 to 6	30	15	12	27	16·1	12 9	29·0	55·6	44·4	69·2	51·7	60·5	80·3	3·71
IV	Early March	24th Feb.	105	3 to 4	17 to 19	1½ to 3	24	14	18	32	13 3	17·2	30·5	43·7	56·3	80·5	59·9	70·2	77·7	0·85
V	Late March	12th Mar.	96	3 to 4	14 to 15	1½ to 3	20	18	22	40	18·8	22 9	41·7	45·0	55·0	82·0	60·1	71·0	76·4	1·99
	TOTAL ..	..	477	..	..	..	..	76	75	151	..	..	31·4	..	..	..	..	..	..	..

TABLE IV.

Laboratory bred A. minimus.

	Period of experiment.	Date eggs oviposited.	Number eggs oviposited.	Period of immature stages in days. Egg	Larval.	Pupal.	Average immature developmental cycle period in days.	Resulting progeny. Number. Male.	Female.	Total.	Percentage. Male.	Female.	Total.	Sex ratio. Male.	Female.	Meteorological data. Average maximum temperature.	Average minimum temperature.	Average mean temperature.	Average humidity.	Total rainfall in inches.
I	December	1st Dec.	115	4 to 6	19 to 25	4 to 5	31	23	12	35	20·0	10·4	30·4	65·7	34·3	74·2	47·9	61·0	68·7	0·19
II	January	26th Dec.	89	6 to 7	20 to 23	5 to 6	33	19	9	28	21·3	10·3	31·5	67·9	32·1	70·2	46·9	58·3	73·4	2·26
III	February	23rd Jan.	86	5 to 7	17 to 21	3 to 5	29	9	14	23	10·5	16·2	26·7	39·1	60·9	69·2	51·7	60·5	80·3	3·71
IV	Early March	24th Feb.	87	3 to 4	16 to 18	1½ to 3	23	14	16	30	16·1	18·4	34·5	46·7	53·3	80·5	59·9	70·2	77·7	0·85
V	Late March	12th Mar.	116	3 to 4	13 to 15	1½ to 3	20	11	21	32	9·5	18·1	27·6	34·4	65·6	82·0	60·1	71·0	76·4	1·99
	TOTAL ..	..	..	..	..	..	..	76	72	148	..	..	31·0	..	..	..	..	..	..	..

Boyd (1930), in quoting Lamborn (1922), suggests that the inequality in the developmental rate of the progeny of a given female is an important factor in ensuring the emergence of adults during a long interval of time, where breeding is adversely influenced by cool temperatures, and this inequality of development guarantees the continuance of a particular strain. We have shown that such an inequality of development in the larval span occurs naturally in a perennial stream, and, with the presence of differing natural water conditions, conducive to the breeding of *A. minimus*, this inequality of production may be emphasised, thus doubly ensuring the guarantee of the continuance of the species over that period when breeding is *slowed up* by the prevailing lower temperatures of water in which breeding is found to occur in the plains of Assam during December, January and February.

We have noted that in (*a*) swampy seepages, (*b*) 'all weather'* (small) streams and (*c*) perennial (moderately large) streams, all of which breed *A. minimus* during the cold season, (*a*) and (*b*) are the more favoured habitats. On the other hand, (*a*) and (*b*) are more liable to become dry, particularly in areas where the subsoil water is low and where there is no cold weather rainfall. Breeding naturally stops in (*a*) and (*b*) when cold weather drying takes place. In places where this occurs annually, but where there is a perennial stream, it follows that the perpetuation of the species can be locally maintained in (*c*).

It, therefore, follows that the numerical prevalence of *A. minimus* adults which we found in March (*vide* Table II), when more favourable meteorological conditions for transmission were present, will be governed by the presence or absence of (*a*), (*b*) or (*c*) breeding places, either separately or collectively. These factors have significant bearing upon the groups A, B and C established in a previous paper (Rice, 1935*a*).

Rice (1935*b*) noted that there were two peaks of *A. minimus* larval density: (*a*) during the pre-monsoon period and (*b*) during the post-monsoon period in November when the larval density was high and, from thence onwards until March, we found the numerical status of *A. minimus* larvæ, of all instars, and including pupæ, to be sufficiently high to preclude the possibility of abrupt disappearance of the species during any period of the cold weather months. On the other hand, a sudden increase in numbers of the species could be easily foreseen with the onset of any favourable condition, be it an increase of suitable water area, or more favourable meteorological conditions.

II. Oviposition.

Between 15th January and 15th February, during a period when the mean maximum temperature was 70·2°F., the mean minimum temperature 47·1°F. and the mean relative humidity 74·5 per cent (i.e., the lowest values during the year), gravid specimens of *A. minimus* were placed separately in 3×1 inch specimen tubes, as described in No. I of the breeding experiments.

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*'All weather' stream.—A small stream with almost continuous grassy edges, relatively rich in plankton and which may, or may not, be perennial according to the amount of local cold weather rainfall.

Twenty oviposited voluntarily, and the number of eggs laid by each individual is shown in Table V.

TABLE V.

Egg counts—A. minimus.

(15th January to 15th February, 1936.)

108	96	87	115	99
89	88	115	92	118
86	99	93	96	85
105	116	90	81	84

Largest number	..	118
Smallest number	..	81
Average number		97

To assure ourselves that oviposition occurs voluntarily and is not forced by the female being enclosed in the tube described, gravid females were liberated into separate 12 × 12 × 12 inch cages placed in a natural stream, such as previously described, where they readily oviposited.

III. Fertility.

To check fertility, each batch of eggs was placed in a separately prepared enamel dish and larvæ were hatched in each instance. It is thus seen that the gravid female oviposits voluntarily even under conditions where the temperatures are at their lowest point, and that the ova are fertile. There is, therefore, no reason to suppose that the fertility of *A. minimus* ova is not constant at all times of the year in the plains of Assam under the prevailing meteorological conditions.

IV. Effect of meteorological conditions upon resulting progeny.

In Tables III and IV, it is seen that 31·4 and 31·0 per cent of eggs, deposited respectively, reached the adult stage during all periods of the four months of the cold weather experiments. On studying the monthly resulting progeny, it becomes apparent that there is close correlation between the mean temperatures prevailing and the numbers of progeny production. Relative humidity, or the light rainfall in short irregular periods, such as were experienced during the cold weather months, would appear not to have had any effect upon increasing or decreasing the numbers of progeny reaching maturity *from any single batch of eggs*. Light rainfall would, however, by the formation of larger areas of seepages favourable to breeding, tend to increase the numbers of progeny *as a whole*.

The stream breeding experiments show the relationship of temperature to the numbers of progeny which were produced from a given number of eggs bred under as nearly natural conditions as possible. We realise that in nature, with the prolonged larval developmental cycle in the cold weather months, the numbers of progeny reaching maturity might have been appreciably reduced because of the attacks of predaceous enemies.

SEX RATIO OF PROGENY.

That the sex ratio of the resulting progeny from any single batch of eggs may be influenced by lowered temperature seems possible. Among the stream

bred groups, it will be seen in Table III that males predominated over females during December, January and February in the ratio 6·3 : 5, while during March, the sex ratio was reversed, females predominating in the ratio 5 : 4.

Among the laboratory bred groups, it will be seen in Table IV that the changes in the sex ratio were altered from a predominance of male progeny in December and January (ratio 2 : 1) to a predominance of female progeny in February and March (ratio 3 : 2).

From these data, it would appear that there may be an alteration in the sex ratio occasioned by reduced mean temperatures and that female predominance is made apparent somewhere between February and March.

As such an alteration of sex ratio would tend to produce a greater proportion of female progeny in March, it is possible that the effect of temperature upon such an increase might be responsible to some extent for favouring transmission of malaria from this period onward.

From our experiments it becomes apparent that *A. minimus* continues to breed throughout the coldest weather, under the temperature and humidity conditions prevailing in the plains districts of Assam at this time. That there is a slowing up of the period of the immature developmental cycle during the coldest months has been shown. There are no evidences of hibernation or 'over-wintering' in the immature stages, but *A. minimus* continues its developmental cycle uninterrupted throughout the entire cold weather season. Ramsay (1930*b*) states that 'Cachar anopheline mosquitoes spent the greater part of their life history during December, January and February in the larval stage'. This statement implies 'over-wintering' in the larval stages. Our investigations, undertaken in a part of Assam where temperatures remain low for longer periods than in Cachar, give results contrary to his findings.

We have noted that in the coldest months there is an inequality in the developmental rate in the larval stages and that, with the presence of differing natural water conditions, this inequality of production of progeny will be emphasised. These factors not only result in the constant emergence of adults to continue their activities, but guarantee the carry over of the species during the dry cold weather months when areas suitable for breeding are proportionately small, or nearly absent, and the developmental cycle retarded.

Our investigations have shown that as a result of continuous breeding, notwithstanding the low minimum temperatures experienced in the Assam plains, there is maintained a constant supply of adult *A. minimus*. The number of female adult *A. minimus* present during any particular period of the cold weather months is dependent upon (*a*) the extent of suitable breeding areas present, (*b*) the rate of larval development, and (*c*) the possible difference in sex ratio of emerging adults. During the colder months, when there is little rain, the breeding places are reduced in area, and the larval developmental period is lengthened, so that the larvæ are more apt to be subjected to the attacks of predaceous enemies. There is also, at this period, a predominance of males emerging. Due to these factors it is seen that, although always present, the female catches of *A. minimus* may be found in comparatively reduced numbers during the coldest months, more especially in the group B areas described by Rice (1935*a*).

With the rising temperatures prevailing from about mid-February onwards, there is a shortening of the period of developmental cycle, and the

subsequent irregular short periods of rainfall in March extend the already existing breeding areas, thus ensuring sudden numerical increase in the adult population. Coincident with this increase in numbers of adults, there is evidence of a reversal of sex ratios, and an overlapping of generations which are derived from (*a*) those surviving from the cold weather breeding prior to mid-February and (*b*) those that have emerged from mid-February onwards.

II. ADULT INVESTIGATIONS AND OBSERVATIONS.

In order to obtain a basis for the evaluation of certain pertinent factors, two experiments were inaugurated to determine: (A) the approximate age and cold weather activities of *A. minimus* when caught in nature, and (B) the possibility of transmission taking place during the cold weather months when night (minimum) temperatures were below 60°F.

(A) THE AGE AND COLD WEATHER ACTIVITIES OF *A MINIMUS* IN NATURE.

METHODS OF INVESTIGATION.

A single coolie house was selected as an observation station for the systematic and regular collections of adults. Collections were made once weekly from 8 a.m. to 8-15 a.m. by the same collector in each instance. This coolie house was located at a distance of approximately 100 yards from the nearest breeding place of *A. minimus*, which was an 'all weather' stream and which we anticipated would contain running water throughout the cold weather. Unfortunately, after about two months, it became apparent that this stream would soon dry up. Although searches in this observation station were continued up to 31st March, it seemed necessary, in order to continue our observations uninterrupted, to select a second observation station, which was done on 1st February. The second observation station was also a coolie house located about 100 yards from a nearby perennial stream, which had also, in its close vicinity, a swampy seepage.

Our object was to determine the approximate age of all specimens of *A. minimus* on the day of catch during the entire investigation period (December to March), by studying the wing grades, according to the methods described by Perry (1912), and the ovarian stages, according to the method of Christophers (1911). We also examined the gut contents for the presence or absence of blood, to determine whether the adults caught had fed under the meteorological conditions prevailing. All females were dissected on the same day they were caught. Species other than *A. minimus*, although caught and dissected during the periods of searches, are not included in the data presented.

I. Wing grades.

In grading the condition of wings of *A. minimus* on capture, we have followed Perry's (1912) classification, viz.:—

Grade I .. Specimens with the wing well marked and with the wing fringe practically complete.

Grade II .. Specimens with the wing fairly well marked but with the wing fringe somewhat worn.

Grade III .. Specimens with the wing decidedly shabby and the wing fringe very much worn.

Grade IV .. Specimens with the wing actually threadbare.

Perry (1912) noted that the progressive deterioration of the wing is a very useful indication of the relative age of anopheline mosquitoes, and he states, 'the youngest mosquitoes were found only in Grades I and II'.

II. Ovarian developmental stages.

In noting the stage of ovarian development of *A. minimus* at the time of capture, we have followed Christophers' (1911) classification as modified by Barraud (1934).

Stage I	..	'Ovum' (as represented by the nucleus and the clear space around this) without any 'granules'. Indistinguishable except by position from the nurse cells.
Stage II	..	'Ovum' shows yelk granules, nucleus still visible. Ovum occupies about one-third of the follicle.
Stage III	..	'Ovum' full of coarse granules, nucleus obscured. Ovum (mapped out by granules) occupies from half to two-thirds of the follicle.
Stage IV	..	The follicle has become elongated, and has begun to resume the shape of the mature egg. The ovum (mapped out by granules) occupies four-fifths or more of the follicle. Nurse cells less conspicuous.
Stage V	..	The floats at the side of the egg (follicle) can be distinguished. These, and the chitinous envelope generally, are formed from the follicular cells. The egg becomes ready for oviposition.

In freshly emerged anophelines, the ovaries are always in Stage I; which stage is observed for not more than 48 hours and *once* only in the mosquito's life history. Stage II, and subsequent stages, may be found among young mosquitoes or among those which have laid their second, or even subsequent, batches of eggs. When retained mature ova are not found in a large number of examinations, it suggests that mosquitoes have not previously oviposited but, when retained mature ova are found, it is an unmistakable evidence of previous oviposition.

Christophers (1911), when observing the developmental period of ovaries in *A. rossi* (*subpictus*), during a period of most active development (Punjab-August), summarised the results of approximate time taken for ovarian development as follows :—

Stage I	..	Follicles undeveloped; salivary cells immature	12 hours.
Stage II	..	First appearance of yelk granules ..	36 hours.
Stage III	..	Obscuring of the nucleus by yelk ..	4th day.
Stage IV	..	Commencing elongation of follicle ..	5th day.
Stage V	..	Appearance of floats	6th day.

Our observations were made during a period when the ovarian developmental cycle might reasonably have been expected to be slowed up, but this factor will not alter the significance of finding specimens with ovarian development in Stage I showing the presence of recently emerged adults, or the

complete absence of any specimen having retained ova among the observation station series of *A. minimus* catches, suggesting the presence only of primiparous specimens, i.e., comparatively young females.

III. Examination of gut contents.

To determine whether the feeding stimuli were active under the meteorological conditions prevailing in the cold weather, the gut contents of all specimens were examined for the presence or absence of blood. These were classified as follows :—

Gut contents I ..	.. free from blood.
Gut contents II ..	.. freshly ingested blood.
Gut contents III ..	.. partially digested blood.
Gut contents IV ..	.. old and freshly ingested blood.
Gut contents V ..	.. nearly completely digested blood.

IV. Dissection.

Dissection of *A. minimus* for evidence of sporozoites and/or oocysts was made on the same day the specimens were caught.

V. Meteorological conditions.

The meteorological conditions were recorded as prevailing during the experiments.

RESULTS OF OBSERVATIONS.

The details of the findings among adults captured in Observation Stations I and II are given in Appendices I and II respectively. The summarised findings are given in Tables VI to XII.

OBSERVATION STATION I—FINDINGS.

PERIOD OF OBSERVATIONS : 7TH DECEMBER, 1935, TO 21ST MARCH, 1936.

I. Wing grades.

TABLE VI.

Grade.	Numbers found by grade.	
	Females.	Males.
I	14	1
II	35	1
III	1	0
IV	0	0
TOTAL	50	2

II. Ovarian stages.

TABLE VII.

Stage.	Numbers found by stage.	
I	2	No retained ova found.
II	13	
III	3	
IV	24	
V	8	
TOTAL	50 females	

III. Gut condition.

TABLE VIII.

Gut contents.	Numbers: Gut contents according to condition.
I. Free from blood	2
II. Freshly ingested blood ..	20
III. Partially digested blood ..	9
IV. Old and freshly ingested blood	16
V. Nearly completely digested blood	3
TOTAL ..	50 females

IV. Results of dissections—50 females.

No sporozoites or oöcysts found.

V. Meteorological conditions.

Range of maximum temperatures .. .. 65°F. to 75°F.
Range of minimum temperatures .. .. 40°F. to 60°F.
Range of relative humidity .. .. 55 to 94.

During the first eight weekly searches, i.e., from 7th December to 25th January, specimens were caught regularly but, with the commencement of drying up of the 'all weather' stream in mid-January, *A. minimus* were absent or difficult to find, although extensive breeding places were present at a distance of not more than one half mile from this house, thereby indicating the short range of flight of *A. minimus* to this observation station in the cold weather season.

I. Wing grades.

Following the described method of estimating the age of the mosquitoes by the Wing Grades, we found 15 to be in Grade I, 36 in Grade II and 1 in Grade III, as shown in Table VI. From these findings, it is seen that, during the period before breeding ceased by virtue of the stream drying up,

young adults were constantly emerging and betaking themselves to this nearby human habitation.

Finding only one specimen in Wing Grade III and none in Grade IV suggests that adults emerging during the investigation period were not long-lived. That there is no evidence of adult hibernation or 'over-wintering' in this observation station during the investigation period among *A. minimus* bred out in nature at any period is shown. Only a small proportion of males to females was caught in this human habitation. This phenomenon is well recognised, but the presence of males, even in small numbers, is contributory evidence of the continuation of active cold weather breeding.

II. Ovarian stages.

In Table VII, showing the ovarian stage findings, it is seen that 2 of the 50 female catches were in Stage I, that is to say, not more than 48 hours old at the time of capture. Eight were in Stage V, i.e., gravid, and the remaining 40 were in intermediate stages of ovarian development (Stages II, III and IV). The presence of ovaries in all stages of active development is evidence that females of *A. minimus* do not pass through the winter in any one particular stage of ovarian development, but that this developmental cycle is going on to maturity uninterrupted under the meteorological conditions prevailing.

No adult, on dissection, was found to have retained ova, therefore we presume that we were dealing with relatively young primipara for, as we shall show later, in the groups kept for 8 to 18 days before dissection, multiparous *A. minimus* with retained ova were commonly found. We, therefore, conclude by the presence only of primiparous *A. minimus,* that adults were emerging continuously and were not long-lived. The numerical decrease of the species noted later was made apparent by virtue of the drying up of the nearby breeding place, and *not* because of the low temperatures, as we will show in the finding of Observation Station II.

III. Gut contents.

Among the 50 specimens of female *A. minimus* examined (*vide* Table VIII), the gut contents of all except two showed blood in one or other stage of digestion. These findings give evidence that the feeding stimulus continues to be active. The two specimens excepted (Nos. 13 and 17, Appendix I) were both gravid and in Wing Grade II and must therefore have previously taken blood which had been fully digested. The presence of freshly ingested blood in 20 specimens, and proof of at least two feeds by the presence of old and freshly ingested blood in 16 specimens, is weighty evidence that the feeding stimulus continues to be active throughout the cold weather months. In no specimen was there evidence of fat storage.

IV. Dissections.

That, on dissection, no sporozoites or oöcysts were found in this group was to be expected, as we have shown we were dealing with primiparous *A. minimus*, whose wing condition, with one exception, was in Grade I or II, and they were probably too young to have developed discernible oöcysts and hence to have developed sporozoites in that period when the sporogony cycle is slowed up by the reduced temperatures prevailing and during their apparently short lives.

V. Temperature and humidity.

The conditions of temperature and humidity may be seen in the Graph

OBSERVATION STATION II—FINDINGS.

PERIOD OF OBSERVATIONS : 1ST FEBRUARY TO 28TH MARCH, 1936.

I. Wing grades.

TABLE IX.

Grade.	Numbers found by grade — Females.	Numbers found by grade — Males.
I	10	1
II	20	0
III	0	0
IV	1	0
TOTAL	31	1

II. Ovarian stages.

TABLE X.

Stage.	Numbers found by stage.	
I	0	No retained ova found
II	4	
III	4	
IV	18	
V	5	
TOTAL	31 females	

III. Gut condition.

TABLE XI.

Gut contents.	Numbers: Gut contents according to condition
I. Free from blood	1
II. Freshly ingested blood ..	9
III. Partially digested blood ..	14
IV. Old and partially ingested blood	1
V. Nearly completely digested blood	6
TOTAL ..	31 females

IV. Results of dissections—31 females.

TABLE XII.

Series number ..	22	25	26
Caught ..	28-3-36	28-3-36	28-3-36
Oöcysts ..	+ +	+ +	−
Sporozoites ..	−	−	+ +
Wing grade ..	II	II	IV
Ovarian stage ..	V	V	IV
Gut contents ..	Nearly completely digested blood.	Nearly completely digested blood.	Freshly ingested blood.

V. Meteorological conditions.

Range of maximum temperatures .. .. 70°F. to 83°F.
Range of minimum temperatures .. .. 48°F. to 64°F.
Range of relative humidity .. .. 59 to 96.

As previously stated, this second observation station was selected on 1st February, because the breeding area adjacent to Observation Station I was drying up.

I. Wing grades.

All specimens collected, with one exception (*vide* Table IX), were found in Wing Grades I and II; the exception being in Grade IV. Similar to the findings in Observation Station I, there is no evidence of adult hibernation or 'over-wintering', but there is evidence that adults were emerging at all periods of this investigation. From the finding of one specimen in Wing Grade IV it might be inferred that a very small proportion of female *A. minimus* present may be carried over the winter in a multiparous stage and are therefore not unlikely, potentially infective.

II. Ovarian stages.

The ovarian stage findings (*vide* Table X) show that no specimen caught was in Stage I, therefore we may assume that all were over 48 hours old at the time caught. All specimens were in Stages II to V, again showing, as in the case of Observation Station I, that ovarian development was progressive and not confined to any one particular stage.

III. Gut contents.

The gut contents showed only one of 31 specimens to be free from blood (*vide* Table XI), therefore the feeding stimulus is shown to be active. The one exception (No. 1 of Appendix II) was a gravid female, Wing Grade II, and therefore must have previously fed on blood.

IV. Dissections.

Results of dissections are shown in Table XII. The finding of two *A. minimus* on the day caught, i.e., 28th March, with oöcyst infections in young specimens both in Wing Grade II, shows that the infection must have been acquired not later than early March.

The sporozoite infection found on the date of capture (28th March) was in an *A. minimus* in Wing Grade IV. This infection might conceivably have been carried over the winter months from infection acquired early in the cold weather, but, as we have shown previously, there is evidence to support a conclusion that *A. minimus* is short-lived and does not hibernate, thus we consider that the possibilities of this insect having survived throughout the cold weather are problematical.

V. *Meteorological conditions.*

The conditions of temperature and humidity are shown in the Graph.

INTERPRETATION OF FINDINGS.

Both Perry's (1912) wing gradations and Christophers' (1911) stages of ovarian development have been accepted as criteria in the determination of the probable age of anophelines. The presence of blood in varying stages of digestion in nearly all catches of *A. minimus* throughout the cold weather months must necessarily show that the feeding stimulus continues active. The cattle population in the area under investigation was extremely small, and our catches were made from the human habitation observation stations, therefore we assume that the blood feeds were from human sources in most, if not in all, cases.

We have shown by these criteria that, under the variable meteorological conditions present in the plains districts of Assam from November to March, the population of *A. minimus* during this period, in the presence of suitable breeding places, is regularly being reinforced by the steady production of newly hatched adults and that the feeding stimulus continues active. Even the youngest adults in this series of 81 female catches were found to have blood in one or other stage of digestion.

That recently emerged *A. minimus* are attracted to human habitations where they continue to take blood feeds would appear therefore, even in the coldest season when minimum outdoor temperatures are as low as 43°F., to be a normal sequence of events. That the indoor minimum temperatures in human habitations are much higher than are the outdoor temperatures is obvious, as the habitations are generally roofed with thatch, are overcrowded, ill ventilated and often have fires for cooking in the morning and evening. It would appear, therefore, that *A. minimus*, after emergence, exhibited some form of thermotropism and is thus attracted to these warmer habitats (micro-climates*).

The investigations, through catches made in these observation stations, thus determine that *A. minimus* is capable of, and does, ingest blood throughout the cold weather season, and that these blood feeds are not stored in the form of fatty reserves. These findings, taken in conjunction with the presence of male *A. minimus* and the absence of any hibernating attitude, show that our catches were not hibernating or 'overwintering' females. Swellengrebel (1929) drew attention to the importance of a condition where ovarian development ceases but feeding continues, a condition which he terms '*gonotrophic dissociation*'. He noted that, in this stage, anophelines might remain in a house and continue

* Micro-climates.—Indoor temperatures higher than outdoor cold weather temperatures due to environmental factors.

to feed but without any call to leave the house for purposes of oviposition. That our catches were not in a state of 'gonotrophic dissociation' is shown by the presence of *all* stages of ovarian development to maturity of the ova, and that voluntary ovipositions of fertile ova continued throughout the cold weather months as we have previously shown.

From these collective findings we can only conclude that *A. minimus*, throughout the cold weather months, does not fashion new modes in its immature or adult life history. Thus by *A. minimus* continuing to ingest blood in an area where the known gametocyte index is high throughout the cold weather, the possibilities of recently emerged *A. minimus* acquiring and transmitting infection, especially under suitable micro-climates, cannot be excluded.

(B) THE POSSIBILITY OF TRANSMISSION DURING COLD WEATHER, WHEN MINIMUM TEMPERATURES ARE BELOW 60°F.

METHODS OF INVESTIGATION.

I. Laboratory transmission experiments.

II. Observations on transmission as it may occur in nature and studied in the light of wing gradations, ovarian stages and the presence or absence of oöcysts and/or sporozoites on dissection of *A. minimus* captured in human habitations.

I. Laboratory transmission experiments.

Only laboratory bred adults of *A. minimus* from three to five days old were employed for feeding experiments, to preclude the possibility of any previous natural infection. For feeding mosquitoes, only malignant tertian carriers with heavy gametocyte infections were selected throughout the series. Fed mosquitoes were kept in Barraud cages, under unheated conditions in an open-air laboratory where the temperatures corresponded closely to the outdoor temperatures.

For the purpose of feeding mosquitoes, specimens to be fed were placed singly in 3×1 inch tubes which were inverted over an exposed and easily accessible part of the body of the gametocyte carrier. The experimental insects had not previously been subjected to starvation, for raisins and water were always present in their cages. It was noted that the majority of experimental *A. minimus* took blood feeds readily. After being given the recorded one or more blood feeds they were placed in Barraud cages where they were subsequently only fed on raisins and water until they were dissected. Three series of experiments were undertaken, one each in January, February and March.

Tables XIII to XV give particulars of specimens of *A. minimus* fed 1, 2 or 3 times during January, February and March. Our original object was to retain specimens for 14 to 21 days after the first blood feed, before dissecting them with a view to allowing time for sporozoites to develop. In the case of those 7 specimens where dissections were carried out before 14 days from the first feed, this was necessary as the specimens appeared to be dying.

TABLE XIII.

January series.

Serial number.	Date of feed.			Meteorological condition between first feed and dissection.			Dissection.		Infection.	
	First.	Second.	Third.	Mean maximum temperature.	Mean minimum temperature.	Mean relative humidity.	Date.	Days after 1st feed.	Oöcyst.	Sporozoite.
1	2-1-36	..	..	69·1	48·3	74·9	13-1-36	11	—	—
2	2-1-36	..	..	69·1	48·3	74·9	13-1-36	11	—	—
3	2-1-36	..	..	70·1	47·7	74·6	17-1-36	15	—	—
4	2-1-36	..	..	69·5	47·8	74·5	23-1-36	21	—	—
5	2-1-36	..	..	..	..	..	Died	..	..	..
6	2-1-36	..	..	..	..	..	Died	..	..	.
7	6-1-36	8-1-36	..	70·9	47·6	72·8	15-1-36	9	—	—
8	6-1-36	8-1-36	..	70·0	47·4	69·3	23-1-36	17	—	—
9	6-1-36	8-1-36	9-1-36	70·0	47·4	69·3	23-1-36	17	—	—
10	6-1-36	9-1-36	10-1-36	..	..	..	Died	—	..	..
11	8-1-36	9-1-36	10-1-36	70·9	47·0	72·3	21-1-36	13	—	—
12	8-1-36	9-1-36	..	70·9	46·9	72·6	29-1-36	21	—	—
13	8-1-36	10-1-36	..	..	..	..	Died	—	..	..
14	10-1-36	..	..	69·1	47·8	74·0	23-1-36	13	—	—
15	10-1-36	..	..	70·5	46·9	73·1	29-1-36	19	—	—
16	10-1-36	..	..	..	..	..	Died	..	..	.

TABLE XIV.

February series.

Serial number.	Date of feed.			Meteorological condition between first feed and dissection.			Dissection.		Infection.	
	First.	Second	Third	Mean maximum temperature.	Mean minimum temperature.	Mean relative humidity.	Date.	Days after 1st feed.	Oöcyst.	Sporozoite.
1	1-2-36	..	..	69·8	49·8	78·6	17-2-36	16	—	—
2	1-2-36	..	..	69·6	50·7	80·4	22-2-36	21	—	—
3	1-2-36	..	..	69·6	50·7	80·4	22-2-36	21	—	—
4	1-2-36	..	..	..	..	..	Died	..	..	..
5	1-2-36	..	..	..	..	..	Died	..	..	..
6	4-2-36	6-2-36	..	69·4	47·0	77·1	12-2-36	8	—	—
7	4-2-36	6-2-36	..	68·5	50·1	80·9	18-2-36	14	—	—
8	4-2-36	6-2-36	..	68·9	50·8	81·4	22-2-36	18	—	—
9	4-2-36	6-2-36	..	..	..	..	Died	..	..	..
10	4-2-36	..	..	68·9	50·8	81·4	22-2-36	18	—	—
11	4-2-36	..	..	..	..	..	Died	..	..	..
12	7-2-36	..	..	70·6	52·3	82·8	18-2-36	11	—	—
13	7-2-36	..	..	70·6	52·5	83·1	22-2-36	15	—	—
14	7-2-36	..	..	..	..	..	Died	..	..	..

TABLE XV.

March series.

Serial number.	Date of feed.			Meteorological condition between first feed and dissection.			Dissection.		Infection.	
	First.	Second.	Third.	Mean maximum temperature.	Mean minimum temperature.	Mean relative humidity.	Date.	Days after 1st feed.	Oöcyst.	Sporozoite
1	13-3-36	14-3-36	..	81·9	59·7	75·6	31-3-36	18	+ +	+ +
2	14-3-36	..	..	82·0	60·1	75·7	31-3-36	17	—	—
3	14-3-36	..	..	82·0	60·1	75·7	31-3-36	17	+ +	+ +
4	14-3-36	..	..	82·0	60·1	75·7	31-3-36	17	—	—
5	14-3-36	..	..	82·0	60·1	75·7	31-3-36	17	—	—
6	14-3-36	..	..	..	..	..	Died	..	..	..

The January and February series (*vide* Tables XIII and XIV), in which 11 and 9 specimens respectively survived and were dissected at varying intervals from 9 to 21 days after the first feed, were all found negative for oöcysts or sporozoites.

The March series (*vide* Table XV), of which 5 specimens were dissected at periods of 17 and 18 days after the first feed, showed two *A. minimus* infected with both oöcysts and sporozoites. One of these infected specimens had fed twice on consecutive days; the other had only fed once. The completion of the cycle of sporogony in both cases took not more than 17 to 18 days during a period when the *mean maximum* temperatures were 82°F. and the *mean minimum* temperatures 60·1°F. The average (mean) temperature was 70·1°F.

These two specimens of *A. minimus*, infected from one and two feeds respectively, were the progeny resulting from eggs laid by a gravid female on 14th February. The temperatures under which all the open-air laboratory experiments were conducted were lower than would have been the micro-climates in coolie houses. This finding indicates that in suitable micro-climates within human habitations the sporogony cycle in *A. minimus* may develop to the completed sporozoite stage at any time during the cold weather period. That progeny resulting from eggs deposited in mid-February may become infected under the prevailing temperatures present at this time (as opposed to micro-climates) and may thus become a responsible factor in the dissemination of malarial infections by March, is demonstrated. Where 2 out of 5 specimens of *A. minimus* were readily infected to the infective sporozoite stage, under the meteorological conditions which prevailed up to mid-March, significant transmission could easily be foreseen under outdoor meteorological conditions, but more especially in micro-climates. Anti-larval measures, if not put into operation until mid-March, could have no beneficial effect upon transmission taking place at this time, for significant numbers of *A. minimus* have been shown to be present as a result of active breeding and active transmission can take place.

Had we fed the January and February transmission series in the houses occupied by the gametocyte carrier, and kept the caged specimens under the

existing micro-climates of the houses until the time of dissection, these experiments might readily have been successful. Unfortunately, although this was considered, it was not carried out as we thought that this would amount to incubation. Actually, in nature, such incubation would take place in the micro-climates within houses.

II. Observations on transmission as it may occur in nature.

As has been previously shown (*vide* Table II), 3,249 *A. minimus* adults, inclusive of males, were caught in the area under investigation during the months November to March. Of these, 1,122 were females who had survived and were dissected between 3rd December and 31st March, at varying intervals from 8 to 18 days after their capture. The specimens, until dissection, were kept in Barraud cages and were fed on raisins and water during the period of captivity. After being caught they were retained, before dissection, with a view to allowing time for them to have developed oocysts or sporozoites had they only recently taken an infected blood feed just prior to their respective capture. The irregularity in period of their retention before dissection differed because of the high mortality making it necessary often to dissect specimens which appeared to be dying. On dissection for evidence of infection, each specimen was examined, and a record was made of its Wing Grade and Ovarian Stage. As the retention of the specimens in captivity allowed complete digestion of any blood feeds previously taken, we were unable, in this series, to include the examination of the gut contents. The individual findings are serially recorded in Appendix III.

I. Wing grades.

The Wing Grades are recorded according to Perry's classification as previously described. Table XVI gives monthly particulars according to the period of collection.

TABLE XVI.

Wing grades.

Period of collection.	Number examined.	Wing Grades.			
		I	II	III	IV
25th to 30th November	156	0	74	81	1
December	298	0	69	225	4
January	309	0	86	191	32
February	173	0	26	118	29
1st to 25th March ..	186	0	22	124	40
TOTAL ..	1,122	0	277	738	106

No specimen was found in Wing Grade I for, by being kept for from 8 to 18 days in captivity, their wings showed age deterioration beyond Grade I by the time they were examined.

It will be noted (*vide* Table XVI) that approximately 50 per cent of those catches made in November fell in Wing Grade II. In subsequent months

the percentage found in Grade II was gradually reduced until by March that grade was only represented by approximately 12 per cent. With the finding of a progressive reduction of numbers in Grade II, there was a corresponding increase in the numbers found in Grades III and IV. Actually, in Grade IV there was an increase from less than 1 per cent in November to more than 21 per cent in March. This shift to the right in the Wing Grade percentages gives an indication of the relative slowing down of adult emergences occasioned by the cold weather meteorological conditions which we have discussed elsewhere. This shift to the right in the Wing Grade percentages might also be taken as evidence of the possibility of a carry over of adults from the post-monsoon period of high infection rate, were it not for the fact that among those specimens found infected with oöcysts or sporozoites, or both, none were found in Wing Grade IV until 6th March, by which period the temperatures prevailing were conducive to the longer life of *A. minimus*.

In the Observation Station series, I and II, where we have based the approximate age of *A. minimus* specimens upon the wing gradations *on the day they were captured*, it was found that 82 out of 84 specimens were in Grades I and II and, from the absence of retained ova in any specimen, we concluded that we were dealing with primipara, i.e., obviously young adults.

In this series, retained for subsequent dissection, specimens, after being caught in test tubes, were transferred to Barraud cages where they received no blood feeds, but survived on raisins and water. In the small space provided for them they were kept for periods ranging from 8 to 18 days before examination and dissection. During this period of captivity their wings, due to efforts to liberate themselves, showed progressive deterioration which was in proportion to the lapse of time between their capture and their examination and dissection. These specimens were, for this reason, mainly found in the advanced Grade III. Among these we found multiparous females, for these were from 8 to 18 days older than were those of Observation Station series. We consider that had examinations of the group retained for 8 to 18 days been made at the time of catch, as in the case of the Observation Station groups, the two series would have been comparable as regards age as determined by the wing gradations, and that a considerably larger percentage of the retained group would have been found to have been relatively recently emerged adults in Grade I or II.

These data show that among our 1,122 examinations in this series, there were 106, or less than 10 per cent, of the specimens found in Wing Grade IV (*vide* Table XVI) even when wings were graded after 8 to 18 days captivity. If we had disregarded entirely the observed progressive deterioration of wings due to *A. minimus* being kept in captivity, it is seen that less than 10 per cent of these specimens could have been carried over the cold weather and which might potentially have become infected during the previous post-monsoon active transmission period. Had we found a larger proportion of specimens in Wing Grade IV in this series, or in Wing Grade III among the Observation Station series, we would have been led to the conclusion that *A. minimus* was long-lived under cold weather conditions. Actually, the reverse is the case, and we therefore conclude that few *A. minimus* survive from the previous post-monsoon active transmission period to be a responsible factor in the spring rise of malaria case incidence which makes itself apparent in March and April (Rice, 1935*a*). The findings, together with the continued

presence of male *A. minimus* throughout the cold weather, have led us to the conclusion that we were dealing with adults resulting from continuous cold weather breeding. Thus we also conclude that there is no evidence to support a theory that a significant number of *A. minimus* can survive, infected or uninfected, from the post-monsoon active transmission period until mid-March when infected specimens, upon dissection, assume significant proportions. On the other hand, we have presented evidence which indicates that lowered temperatures reduce the longevity of *A. minimus* adults and we will later, in this paper, produce evidence which indicates that transmission, at least up to the oöcyst stage, can take place under suitable micro-climates during the cold weather in Assam.

II. *Ovarian stages.*

Ovarian Stages I to V are recorded according to Christophers' classification as previously described. In addition to these we have, for the reasons given, included two other classifications, viz.:—

Stage VI .. Those specimens which by ovipositing would have passed to Stage II, but which were actually observed to have *oviposited voluntarily during captivity* and therefore are classified, when subsequently found with developing ova, as multipara.

Stage VII .. Those specimens which were in Stage II, but which had retained ova and were therefore classified as multipara.

Stage VI is included to show that when *A. minimus* arrives at a stage of maturity she oviposits voluntarily regardless of the prevailing cold weather temperature conditions in the Assam plains.

Stage VII is included to show that normal oviposition does take place voluntarily *in nature* during the cold weather and that the specimens in this classification were multiparous insects which had previously deposited one or more batches of eggs.

Table XVII gives the monthly particulars of the Ovarian Stages.

TABLE XVII.

Ovarian stages.

Period of collection.	Number examined.	Ovarian Stages I	II	III	IV	V	VI	VII
25th to 30th November.	156	0	71	3	0	54	16	12
December	298	0	172	0	0	110	10	6
January ..	309	0	95	4	0	182	19	9
February ..	173	0	52	3	0	84	23	11
1st to 25th March.	186	0	86	0	0	57	21	22
TOTAL ..	1,122	0	476	10	0	487	89	60

It will be noted that over 56 per cent of the total specimens examined were in Ovarian Stages V, VI and VII. Rice (1935*b*) found that one or more blood meals were essential for the maturation of the ovaries of *A. minimus*, and from this finding we conclude that 56 per cent of the specimens found in Ovarian Stages V, VI and VII must have received blood feeds prior to their capture to enable the ovaries to have reached maturity during the period of their captivity.

Of the remainder, about 43 per cent were found in Ovarian Stage II. These may be comprised of both primipara and multipara. Those primipara which remained in Ovarian Stage II throughout the period of captivity presumably did so by reason of not having received blood feeds before capture to ensure maturation of ovaries. The multipara found in Stage II were presumably in one or other of the advanced ovarian stages when caught, had oviposited, but had retained no ova and thus reverted to Stage II instead of being classified Stage VII had ova been retained.

Approximately 1 per cent of the specimens were found in the intermediate Ovarian Stage III and none in Stage IV. This phenomenon is in keeping with what would be expected for, among those which had received blood feeds, the ovarian stages had proceeded to Stage V or beyond, during that period of captivity before dissection and ovarian classification. Those which had had no blood feeds remained in the early stages of ovarian development, i.e., Stage II.

In the Observation Station series, we have shown that ovarian development was progressive and not confined to any one particular stage. In this group retained in captivity without blood feeds for 8 to 18 days before classification of ovarian stages, there would be normally (but only if ovarian development was continuing to be active) an unequal distribution of the ovarian grades in which case the advanced grades would predominate. Actually, our findings show this to be the case. There is, therefore, no evidence of any delayed ovarian development such as would be evident were hibernation the rule during the cold weather months.

III. Examination of gut contents.

Gut content examinations were not carried out in these experiments because for 8 to 18 days they had fed on raisins and water only, and any blood previously taken by the specimen under examination would have been completely digested by the time of dissection.

IV. Dissection.

TABLE XVIII.

Period of dissection.	Number dissected.	SPOROZOITES.		OÖCYSTS.		TOTAL INFECTIONS.	
		Number positive.	Per cent positive.	Number positive.	Per cent positive.	Number positive.	Per cent positive.
December	395	7	1·8	19	4·8	20	5·1
January ..	305	1	0·3	6	2·0	6	2·0
February ..	189	nil	—	4	2·1	4	2·1
March ..	233	6	2·6	20	8·6	23	9·9
TOTAL ..	1,122	14	1·2	49	4·4	53	4·7

Table XVIII gives the monthly infection summary of the dissections, and Tables XIX to XXII give complete monthly data (abridged from Appendix III) relative to all infected specimens found throughout the cold weather months.

TABLE XIX.

December infections.

Serial number of specimen.	Date of capture.	Date of dissection.	Condition upon dissection.				Remarks
			Wing grade.	Ovarian stage.	Sporozoites.	Oöcysts	
8	25th Nov.	3rd Dec.	3	5	+ +	+ +	
78	27th "	12th "	3	2	—	+ +	
84	27th "	12th "	3	6	—	+ +	
148	29th "	13th "	2	5	—	+ +	
171	9th Dec.	23rd "	3	5	—	+ +	
175	9th "	23rd "	3	2	+ +	+ +	
185	9th "	23rd "	3	7	+ +	+ +	Retained ova.
189	9th "	23rd "	3	2	—	+ +	
190	9th "	23rd "	3	2	—	+ +	
222	10th "	24th "	3	5	—	+ +	
232	10th "	26th "	3	2	—	+ +	
239	10th "	26th "	3	5	+ +	+ +	
262	10th "	27th "	3	5	—	+ +	
263	10th "	27th "	3	5	—	+ +	
270	10th "	26th "	3	2	+ +	+ +	
276	11th "	25th "	3	2	—	+ +	
327	13th "	25th "	3	2	+ +	+ +	
345	13th "	30th "	3	2	—	+ +	Fully mature oöcysts.
348	13th "	26th "	3	2	+ +	—	
370	15th "	30th "	3	2	—	+ +	

TABLE XX.

January infections.

Serial number of specimen	Date of capture.	Date of dissection.	Condition upon dissection.				Remarks
			Wing grade.	Ovarian stage.	Sporozoites	Oöcysts	
497	6th Jan.	14th Jan.	3	5	—	+ +	
498	6th "	14th "	3	5	—	+ +	
499	6th "	14th "	3	5	+ +	+ +	
574	11th "	21st "	3	5	—	+ +	
575	11th "	21st "	3	5	—	+ +	
576	11th "	21st "	3	5	—	+ +	

In Tables XIX to XXII it will be noted, among *A. minimus* found infected during the entire period of the investigation, that 4, or 7·5 per cent,

TABLE XXI.

February infections.

Serial number of specimen.	Date of capture.	Date of dissection.	Condition upon dissection. Wing grade.	Ovarian stage.	Sporozoites.	Oöcysts.	Remarks.
710	18th Jan.	1st Feb.	3	5	—	+ +	Fully mature oöcyst.
797	3rd Feb.	14th „	3	5	—	+ +	10 oöcysts.
798	3rd „	14th „	3	5	—	+ +	18 oöcysts.
838	11th „	22nd „	3	2	—	+ +	Heavy infection.

TABLE XXII.

March infections.

Serial number of specimen.	Date of capture.	Date of dissection	Condition upon dissection. Wing grade.	Ovarian stage.	Sporozoites.	Oöcysts.	Remarks
901	21st Feb.	6th Mar.	4	2	—	+ +	Mature oöcyst.
908	22nd „	10th „	4	5	+ +	+ +	
921	27th „	8th „	3	5	—	+ +	
962	4th Mar	13th „	4	2	+ +	—	
971	4th „	13th „	2	2	—	+ +	
985	5th „	16th „	3	5	—	+ +	Caught from one house.
986	5th „	16th „	3	2	—	+ +	
987	5th „	16th „	3	2	—	+ +	
988	5th „	16th „	3	2	—	+ +	
1009	7th „	17th „	2	2	—	+ +	
1010	7th „	17th „	3	2	—	+ +	
1011	7th „	17th „	2	5	—	+ +	
1036	11th „	21st „	3	2	—	+ +	
1052	13th „	21st „	3	2	—	+ +	
1080	18th „	28th „	4	2	+ +	—	
1084	19th „	28th „	3	7	+ +	+ +	Retained ova.
1085	19th „	30th „	3	5	—	+ +	
1101	20th „	30th „	4	7	+ +	—	Retained ova.
1103	21st „	30th „	3	2	+ +	+ +	
1117	25th „	31st „	3	6	—	+ +	
1118	25th „	31st „	3	6	—	+ +	
1119	25th „	31st „	3	5	—	+ +	
1120	25th „	31st „	3	5	—	+ +	

were in Wing Grade II; 44, or 83 per cent, in Wing Grade III and 5, or 9·4 per cent, in Wing Grade IV. We have previously discussed the reasons for the high percentage of specimens found in Wing Grade III. We would not expect to find, especially in the cold weather when the sporogony cycle may be slowed up, a high percentage of infections among specimens in Wing Grade II for the reason that in these young specimens, oöcysts, and particularly sporozoites, will not have had time to develop.

Until the March dissections, no infected specimen was found in Wing Grade IV, but, after 6th March, 4 specimens in this Wing Grade were found: one with oöcysts only, three with sporozoites only and one with both oöcysts and sporozoites.

That no infected specimens in Wing Grade IV were found during January, February or until 6th March shows a lack of evidence of any carry over from November of infected *A. minimus* and suggests that, with the higher temperatures prevailing from this time onwards, there was a corresponding increase in the longevity of *A. minimus,* sufficient to account, not only for the maturation of oöcysts, but for the development of sporozoites. At the same time, with increased temperatures during this period, the number of days required for the completion of the sporogony cycle appears to have been reduced. It is thus by the combination of these two factors operating after 6th March that we would expect to find a higher incidence of infections both in the oocyst and sporozoite stages. Evidence that these two factors were operating from early March to increase both the oöcyst and sporozoite percentages of infections is shown in Tables XVIII and XXII.

One infected specimen in Wing Grade II was found in the oöcyst stage on 13th December. No *A. minimus* in Wing Grade II was subsequently found infected until 13th March, but from this date onwards three specimens in this Wing Grade were found infected in the oöcyst stage. These infected specimens were indisputably young adults which had emerged during that period when minimum temperatures were consistently below 60°F. and which had acquired their respective infections from blood feeds which could not have been taken earlier than the latter part of February or early March, as they were caught on the 4th and 7th March respectively. The presence of oöcyst development among these young adults in Wing Grade II is further confirming evidence of a relative acceleration in the sporogony cycle coincident with the increase of temperature in March.

On perusal of Table XVIII, it is seen that the sporozoite, oocyst and total infectivity rates respectively are relatively high during December at a period when the *mean* temperatures were commencing to fall below 60°F. (*vide* Graph). Infections found at this period may have been either recently acquired or from blood feeds taken at the end of the post-monsoon active transmission period.

Subsequently, in January and February when the *mean* temperatures were just below or slightly above 60°F., the sporozoite rate of infection was low (0·2 per cent); the oöcyst rate was reduced to 2 per cent as was also the total infection rate. After early March, when the *mean* temperatures were suddenly increased to 70°F., there was a rapid increase in the sporozoite, oöcyst and total infectivity rates respectively.

From these findings it would appear that, if we consider the effect of temperature upon the retardation or acceleration of the sporogony cycle, and include the time lag period required for infections to become apparent upon dissection, our observations suggest that it is the *mean* temperature and not the *minimum* temperature which is the significant correlative factor in determining the infection rate among the *A. minimus* population present.

In the Observation Station I and II experiments, we have seen that catches were practically all young *A. minimus* (as judged by the wing

gradations), among which active ovarian development and the normal feeding stimulus were unaffected. We have also shown in the series retained in captivity for 8 to 18 days that, where blood feeds had been taken, ovarian development was carried on to maturity, or to oviposition, while the insects were in captivity. We show in Tables XX and XXI that *A. minimus* found infected during January and February were in Wing Grade III and that their ovarian development had in most cases been completed to maturity, i.e., Stage V or beyond. The completion of ovarian development of these specimens dissected in January and February must have been dependent upon the insects having received adequate blood feeds, and the observed fact that insects confined in Barraud cages were in Wing Grade III, together with the evidence of the young age of catches made under the Observation Station series, leads us with confidence to suggest that the *A. minimus* found infected in January and February can only have acquired their infection during the cold weather months when the outdoor *mean* temperatures were below 60°F. and the *minimum* (night) temperatures were below 50°F.

The January and February dissection results with the finding of infections which apparently had been acquired during the period when the minimum temperatures were consistently below 60°F. substantiate a previous suggestion (Rice, 1935*a*) that transmission by *A. minimus* may still continue throughout the cold weather. The evidence presented in this paper thus shows that during the coldest periods *A. minimus* may become infected and the sporogony cycle may be completed to the mature oöcyst stage, at least to the extent of 2 per cent of the specimens examined and that a few may complete the sporogony cycle to the sporozoite stage. Our evidence leads us to believe that the sporogony cycle is not completed to the sporozoite stage in a large percentage of specimens when temperatures are below a mean of 60°F. and that the factors responsible are (*a*) the shorter life period of *A. minimus* and (*b*) the longer period required for the completion of the sporogony cycle.

We have shown (*vide* Table XVIII) that in December there were relatively high percentages of oöcyst and sporozoite infections, being 4·8 and 1·8 per cent respectively. In January and February, the oöcyst rate was 2·0 and 2·1 per cent respectively and the sporozoite rate 0·3 per cent in January and *nil* in February*. When the infection rates found in the dissections in December are considered in conjunction with those of January and February, it is seen that they are not comparable and, judging by the reduction in the respective oocyst and sporozoite percentages during January and February, there are weighty grounds to suspect that there had been more than a fifty per cent mortality by January among the *A. minimus* population which had been alive in December. Among the February dissections, four specimens were found in the oöcyst stage. Had these specimens, which were all in Wing Grade III, become infected from blood feeds taken prior to the season when night (minimum) temperatures were consistently below 60°F., they would have had to survive at least 75, 89, 89 and 97 days respectively, i.e., from before the 17th November. Having failed to find any evidence of hibernation, over-wintering or gonotrophic dissociation and having demonstrated that these specimens were all in Wing Grade III, and that none had retained ova or other

*Four miles away in Doom Dooma town, among thirteen *A. minimus* dissected in February 1935 one specimen was found with sporozoite infection.

indication of their being multiparous *A. minimus,* together with the evidence that we have presented suggesting the short life of this species in the cold weather months, we consider that the weight of evidence is in favour of their having acquired their infection during that period when the night (minimum) temperatures were below 60°F.

In March, the oöcyst and sporozoite percentages were increased to 8·6 and 2·6 respectively and the total infection rate reached 9·9 per cent. In Table XXII it is seen that, until 13th March, only three specimens, two with oöcysts and one with both oöcysts and sporozoites, were found; but after this period, during the remainder of March, the numbers of both oöcyst and sporozoite infections increased rapidly to an oöcyst rate of 10·0 per cent, a sporozoite rate of 3·2 per cent and a total infection rate of 12·9 per cent. We consider that the significant increase in the oöcyst and sporozoite percentages between 13th and 31st March was taking place among those young adults which had emerged during February and early March and which had acquired their infection by the recent blood feeds. Had these infected specimens survived from the previous November their *minimum* ages would have been from 117 to 135 days. With no evidence of hibernation, over-wintering or gonotrophic dissociation, and from the other factors previously given, we conclude that there is no reason to support the theory that *A. minimus* infection acquired during the previous active transmission period is a significant factor in the dissemination of malaria in March or in the annual March or April rise in the malaria case incidence. On the other hand, the finding by 17th March of three oöcyst infections among *A. minimus* in Wing Grade II (i.e., 15 per cent of the total infections found in March) gives indisputable evidence that adults which have emerged in February and early March can be a responsible factor in causing such a rise in the malaria case incidence, thus we conclude that there is no reason to suppose that the infections among those specimens in Wing Grades III and IV had not been acquired from blood feeds taken in February or early March.

If we disregard the evidence of a low degree of transmission during January and February, we still see that, from early March, *A. minimus* can, by this time, become an undoubted factor in the transmission of malaria as is evidenced by our having found a sporozoite rate of 2·6 per cent. Some authors, however, maintain that the sporozoite rate is less accurate than the oöcyst rate when estimating the infectivity index of the carrier species. Swellengrebel and DeBuck (1931), who experimented with benign tertian parasite infections in *A. maculipennis,* concluded that 'in *A. maculipennis,* intestinal infections provide a more accurate estimate of the number of sporozoite carriers than salivary infections, and this probably applies to other species as well'. Iyengar (1931) maintains that 'when both gut infections and gland infections occur side by side, often in the same individual specimen, under such circumstances, oöcyst infections should certainly be included in the total infectivity rate in order to appraise the transmitting capacity of the species'. If these conclusions are accepted, and we take the total infectivity rate as our criterion of the capacity of *A. minimus* as a vector, our investigations would show that from early March onwards, in increasing proportion and in direct correlation to the temperature rises, *A. minimus* becomes an active transmitter of malaria to the extent of 12·9 per cent of the specimens examined from 13th to 31st March. With an infectivity index of 12·9 per cent present

in March and with an adult *A. minimus* density sufficient for 306 specimens to have been collected during this month (*vide* Table II), it therefore follows that the presence of this species, bred at any period from approximately 1st February onwards, can have a very large influence upon the natural increase in the malaria case incidence from early March onwards and, in order to prevent the emergence of these potential adult vectors from 1st February onwards, anti-larval control must necessarily be started in January.

DISCUSSION.

A fundamental basis upon which to formulate any scientific programme of anti-larval control must be founded upon accurate and complete knowledge of the activities of the vector species in all its stages during *all* seasons of the year. Knowledge of the habits of the vector species, particularly with reference to the so-called 'non-transmission' period, is of vital importance, for upon this knowledge must be based the period when anti-larval activities are to be commenced. For Assam, where *A. minimus* is the proved principal vector, such accurate and complete knowledge has not, up to the present, been available.

The cold weather findings recorded here, with complete data, are an effort to correct this absence of accurate knowledge, but our findings are so foreign to conclusions previously published with reference to the cold weather activities of *A. minimus* that it seems necessary and desirable to point out some of the important discrepancies.

Manson and Ramsay (1933) state 'Larval *wintering** in Assam begins roughly when the night (minimum) temperatures have fallen consistently below 60°F., and continues until the night temperatures again rise above this level'. In another portion of this paper they conclude, 'The larvæ are *wintering,* and remain in the larval stage for a very long period, *at least not less than two months and most probably, in many instances, for a considerably longer period** '.

In another paper, Manson and Ramsay (1932) state 'When the night (minimum) temperatures fall below 60°F., it is extremely easy to collect *A. minimus* in its larval stage in its winter breeding resorts, but in its adult form it is very scarce'.

Previous experiments recorded by Rice (1935*b*), and confirmed by stream breeding experiments reported in this paper, show that larval wintering does not take place.

In January, our experiments show that the average larval span occupied 22 to 30 days when the monthly mean minimum temperature was 46·9°F. and the mean maximum temperature was 70·2°F., i.e., during a period when as low minimum temperatures as found anywhere in the plains of Assam were present. From January onwards there was a gradual and continued shortening of the period of the larval span until by late March it was 14 to 15 days.

We have shown that the larval developmental cycle is completed to pupation and adults emerge the entire period of the cold weather under the prevailing meteorological conditions. We have previously shown that in an

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* The italics are ours.

hyperendemic area where breeding places are continually present, adult *A. minimus* are not only *easy* to capture throughout the cold weather but were the predominating species present (*vide* Table II). We have also shown the presence of young recently emerged *A. minimus* at all periods of the cold weather in our Observation Station series.

We have shown that there is no evidence that *A. minimus* adopts a new mode of life in any stage of its existence during the coldest periods. Breeding continues to emergence of adults, ovaries develop and females, upon full maturity, voluntarily lay eggs, which have been proved fertile, indicating that mating has taken place. From these eggs adult progeny have resulted during each month of the investigation.

Ramsay (1930*c*), with respect to the adult, states '......at this period of the year (cold weather) *Anopheles minimus* is rarely seen in the adult stage, unless very carefully searched for; in other words, the chance of infection being transmitted is greatly limited'.

Manson and Ramsay (1933), when speaking of periods when the night temperatures have fallen consistently below 60°F., state that 'adults mainly hibernate during this period'.

Our findings differ from those of Ramsay, and of Manson and Ramsay, in that we found no evidence of any state of hibernation, over-wintering or gonotrophic dissociation, though we have shown that there is evidence of a slowing down of the metabolism throughout the cold weather months.

Ramsay (1930*d*) writes '......when the night temperatures drop below 60°F. the feeding stimulus of anopheline mosquitoes and especially *A. minimus* is inhibited'.

Manson and Ramsay (1932) state that 'temperature by inhibiting the feeding stimulus of *A. minimus* is a limiting factor in the transmission of malaria'. These authors qualify this statement in the same paper by saying, 'Temperature directly affects the feeding stimulus of *A. minimus* as, during the cold weather months, *A. minimus* which had fed were found chiefly in bungalows and hospitals which were heated with fires. It was also found gorged with blood during the warm day in dark coolie huts. Unfed specimens were usually collected from unheated buildings'. In an earlier paper by Ramsay (1930*b*), a statement which conflicts with the above appears, 'During cold weather when the night temperatures drop below 60°F., anopheline mosquitoes and especially *A. minimus* are seldom seen in human habitations in the adult stage'.

We have shown (*vide* Table II) that *A. minimus* adults are present in significant numbers throughout the cold weather and that they feed *freely* in suitable micro-climates and, in these micro-climates found in coolie houses, feeds are usually taken by *A. minimus* in the evening, when, by the presence of fires for cooking purposes, the temperatures, instead of being as low as they are in the open, tend to be relatively higher, which would have the effect of predisposing to the acquisition of infection, by feeds taken from gametocyte carriers.

That the feeding stimulus is *not* inhibited we have demonstrated, for in 78 out of 81 specimens collected during the Observation Station series experiments, blood in some stage of digestion was found in their gut and, in 46

specimens, this was found to be freshly ingested blood. We have further shown that the greater proportion of specimens of the 1,122 dissected after 8 to 18 days had ovarian development advanced to that state which must have been dependent upon their having taken blood feeds during the cold weather months prior to their capture.

From the evidence presented, it is seen that *A. minimus,* by selecting micro-climates in which to reside, keeps the feeding stimulus active even during the coldest periods of the year and thus temperature, in the sense that it inhibits the feeding stimulus of *A. minimus,* is *not* a limiting factor in the transmission of malaria, because this species appears to exhibit some form of selective thermotropism towards these micro-climates, in which environment it feeds freely throughout the cold weather months.

Ramsay (1930*b*) writes regarding transmission, 'The period during which *A. minimus* was found to be infected with malaria in nature was from 14th April to 22nd December......but actually the period during which *A. minimus* was found capable of transmitting malaria, that is, when infected with sporozoites in the salivary glands, was from 14th May to 9th December. It would appear, therefore, that there is in Cachar (Assam) a definite period during the year, when mosquitoes do not become infected with malaria*. This finding is in keeping with the effects of climate on the life history of *A. minimus*'. In this same paper Ramsay says, 'the efficient control of malaria in Assam is therefore chiefly dependent on the control of the breeding areas of *A. minimus* during the period of the year when *A. minimus* can become infected and is transmitting malaria in nature, i.e., from about the middle of April until practically the end of the year'.

Manson and Ramsay (1932) report 'the first infection found in 1931 was on 17th April and the specimen *A. minimus* showed sporozoites in the salivary gland'.

Manson and Ramsay (1933) state '......malaria is not being transmitted during the period of the year when the minimum temperatures are consistently below 60°F.' and, 'from the infectivity rate of *A. minimus* already recorded in previous publications, it is evident that there is a high degree of infection during November, and the finding of a gut infection in *A. minimus* early in April shows that anti-larval work should begin not later than the middle of March in each year'.

Summarising our *A. minimus* findings in relation to transmission, we have shown that :—

(*a*) there is no evidence that this species can survive the cold weather months until March to be carried over from the previous active transmission period either in the uninfected or infected stage, thus there is no evidence of transmission during March from this source.

(*b*) young, recently emerged *A. minimus,* caught on 4th and 7th March, were found to have completed the sporogony cycle to the oöcyst stage. These must have acquired their infection from the blood feeds taken in February or in the first few days of March.

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* During a preliminary survey in Cachar, we found 3 sporozoite and 2 oöcyst infections among 18 *A. minimus* dissected between 12th and 28th March, 1936.

(*c*) on dissection of significant numbers of this species the oöcyst rate (*vide* Table XVIII), moderately high in December (4·8 per cent), was reduced to a lesser degree (2·0 and 2·1 per cent) in January and February respectively, and was subsequently increased to a high degree by March (8·6 per cent). The oöcyst rate was never lower than 2 per cent during any part of the cold weather months. If we accept the finding of oöcysts as evidence of the capability of this species to transmit malaria at a period when they are found, then on this, though as yet unproved, basis this finding presupposes transmission throughout the cold weather months.

(*d*) on dissection of this species, the sporozoite rate was moderately high (1·8 per cent) in December, was reduced to a low degree (0·3 per cent) in January, was *nil* in February, and in March had increased to a significantly high degree (2·6 per cent). From these findings, it is apparent that extreme cold weather temperatures do effect adversely the completion of the sporogony cycle to the sporozoite stage in most cases, but that by March there is a high degree of infectivity in hyperendemic areas under normal meteorological conditions. They also suggest that infection may be acquired at any time during the cold weather months, but under the meteorological conditions prevailing the sporogony cycle, except possibly in micro-climates, advances only to the oöcyst stage.

(*e*) if we consider the effect of temperature upon the completion of the sporogony cycle and include the time lag period required for sporozoite infections to become apparent, our observations suggest that it is the *mean* temperature and not the *minimum* temperature which is the significant correlative factor in the determination of the relative weight of infectivity rate among *A. minimus*.

(*f*) if we consider *A. minimus* to be relatively short-lived during the colder weather, then this in conjunction with the longer period required for the completion of the sporogony cycle are the two main factors responsible for the reduction in the amount of transmission during January and February.

In our infectivity findings, carried out in an hyperendemic area, when contrasted with those reported by Ramsay (1930*a*), and by Manson and Ramsay (1932, 1933), which were from apparently moderately endemic areas, there are some important discrepancies. While some discrepancies in the findings of different workers are to be anticipated when one worker's findings are from an hyperendemic area, and the other's from moderately endemic areas, this factor will not, in any way, alter the bionomics of *A. minimus* where similar meteorological conditions prevail and there is present some suitable breeding area for that species, be it either the so-called 'winter' or 'summer' breeding place described by Ramsay. The fact that there are more areas suitable for breeding in an hyperendemic area will not affect the bionomics of *A. minimus*, but the presence of a smaller number of gametocyte carriers in February and March in the moderately endemic areas in which Ramsay, and Manson and Ramsay, carried out their investigations may have been partly responsible for the conclusions which they have given. Ramsay (1930*b*) recognised that there might be a

discrepancy in his conclusions for he remarks, 'Although, so far, I have been unable to capture any infected mosquitoes during the month of March, practical experience has shown me that malaria is undoubtedly being transmitted on hyperendemic sites during this period of the year'. He explains the possibilities of transmission by saying, 'the essential factors are a high gametocyte index, close proximity to breeding places of *A. minimus* and night temperatures over 60°F.', and states that, 'the difficulty in finding infected *A. minimus* during March, April and May is also increased by the effect of rainfall, as it is during this period of the year that *A. minimus* migrates from its winter to its summer resorts'. He then says, 'further, the low degree of infectivity of *A. minimus* in my dissection records during March and April was, to a large extent, due to this species being caught in areas with a low gametocyte index'.

Conclusions on the bionomics of *A. minimus* as they affect transmission, derived from dissections carried out in areas where infections may be reduced from factors other than the meteorological, cannot be accepted as an accurate representation of the true bionomics of this species. An accurate evaluation of the true bionomics of *A. minimus*, and its relationship to transmission as affected by the cold weather meteorological conditions in Assam, requires an investigation in an area where the essential factors, without which transmission cannot occur, are constantly present and are subject only to such variation as is imposed by climatic conditions.

We have tried to fulfil these requirements by selecting for our observations an hyperendemic area where the physical conditions throughout the year were suitable for *A. minimus* breeding and adult emergences, and where the third factor favouring transmission, namely, a high gametocyte index, was constantly available. The meteorological conditions alone were subject to variation.

We consider that any scientific recommendations for the period of the year at which to commence anti-larval control directed specifically against *A. minimus* should be founded upon observations on the bionomics of, and the possibility of transmission by, that species conducted in an area where no factor other than meteorological will mask the findings upon which to formulate a foundation for scientific and sound recommendations.

In advocating the period at which anti-larval control should be commenced (based on his work in Cachar, Assam), Ramsay (1930*a*) concludes, (*a*) 'the efficient control of malaria in Assam is dependent on the control by anti-larval measures of the *summer* breeding places of *A. minimus*, i.e., during the period of the year when *A. minimus* can become infected and transmit malaria', and (*b*) 'the period of infectivity in nature is from about the middle of April until practically the end of the year'*. Subsequently, on observations in Upper Assam, Manson and Ramsay (1933) state, '......the finding of gut infection in *A. minimus* early in (14th) April shows that anti-larval work should begin not later than the middle of March in each year'.

Ramsay (1930*a*) and Manson and Ramsay (1933) have based their criteria of the period at which to start control measures on the finding of an oöcyst and a sporozoite infection respectively during April, the earliest period at which they found infections when working in apparently moderately endemic areas. If this reasoning be accepted, then, on our finding of no less

* As previously stated, we found 3 sporozoite and 2 oöcyst infections among 18 *A. minimus* collected in Cachar and dissected between 12th and 28th March, 1936.

than 2 per cent of oöcyst infections during all periods of the cold weather months, it would become necessary to continue anti-larval control uninterrupted throughout the year, for it is recognised by all workers that both oöcyst and sporozoite infections are present in *A. minimus* in Assam during the months April to November.

Although *A. minimus* adults bred out in January and February may not develop sporozoites in a sufficient number of specimens to be able to transmit malaria to a significant degree during these months, they do, during this period, continue to partake of blood meals and 2 per cent have been shown to be potentially infective at least to the oöcyst stage of the sporogony cycle. As soon as meteorological conditions conduce to transmission, by shortening the period required for completion of the sporogony cycle and lengthening of the life span of the vector, the residual *A. minimus* population, some of which have, as we have seen, been infected to the early stages of the sporogony cycle, may then continue the development of their respective infections to the sporozoite stage, when active transmission can readily be foreseen. That this sequence of events can take place in nature is apparent from perusal of Table XXII, where specimens caught in February, before *minimum* temperatures had reached 60°F., were, when subsequently dissected on 6th, 8th and 10th March, found to have fully developed oocysts or oocysts and sporozoites. None of these specimens could have taken blood feeds subsequent to the period when *minimum* temperatures had reached 60°F., as they were fed only on raisins and water during the entire period of their respective captivity.

Even if we unwarrantably discount entirely the oöcyst infections acquired in January or February and their subsequent potential effect upon active transmission in March, we cannot disregard the residual population of adult *A. minimus* which have emerged during January and February and are present in March when meteorological conditions become suitable for active transmission. This *A. minimus* population will be available, unless cold weather anti-larval control measures reduce the adult population, to become potentially infected and subsequently infective wherever gametocyte carriers are present, be that area one with a high or low gametocyte index.

Whether the optimum meteorological conditions for active transmission are considered to be a *minimum* of 60°F , or a *mean* of 60°F., do not affect the findings given in Table XXII and in Appendix III. By these findings it is manifest that three *A. minimus* in Wing Grade II, which were bred out before the *minimum* temperatures reached 60°F., were found in the infected oöcyst stage on 13th and 17th March respectively These specimens must have acquired their infections either in February or during the first few days of March as they were captured on the 4th and 7th March respectively. Other older specimens in Wing Grades III and IV found infected during March, when the sporozoite rate was 2·6 per cent, the oöcyst rate 8·6 per cent and the total infectivity rate 9·9 per cent, were manifestly adult specimens bred out during February, or possibly during January, from larvæ present (in the breeding areas present) in both January or February. From every aspect of our studies of the cold weather bionomics of *A. minimus* in all stages of its existence and from our observations in connection with transmission, we conclude that anti-larval control directed against this species must be commenced not later than 15th January during each year to be effective in reducing the initial rise in the malaria case incidence during March and April.

CONCLUSIONS.

1. The observations and findings described indicate that anti-larval operations directed specifically against *A. minimus*, to be effective in preventing the annual March-April rise in the malaria case incidence in the plains of Assam, should be started not later than 15th January annually.

2. *A. minimus* bred out in January and February form a sufficient nucleus of this species so that by early March, when the prevailing mean temperatures conduce to the completion of the sporogony cycle to the sporozoite stage, they can be responsible for active transmission after that period.

3. Stream breeding experiments, with appropriate laboratory controls, show that *A. minimus* does not winter in the larval stage.

4. Due to continuous cold weather breeding, notwithstanding the low minimum temperatures experienced in the Assam plains, there is maintained a constant supply of adult *A. minimus* throughout the cold weather.

5. Studies of the wing grades, ovarian stages and gut contents of adult *A. minimus* from December to March reveal no evidence of hibernation, overwintering or gonotrophic dissociation.

6. The detection of blood in different stages of digestion in 96 per cent of *A. minimus* caught at regular intervals from December to March and dissected on the same day they were caught and, from the observation that ovarian development continued uninterrupted in 1,122 specimens dissected 8 to 18 days after capture, where the ovarian development observed must have been dependent upon blood feeds having been taken gives evidence that the feeding stimulus of this species is not inhibited by the minimum temperatures prevailing when suitable micro-climates are available.

7. There is no evidence to support the view that infected or uninfected *A. minimus* adults are carried over in the hibernating or other stages from November to March to be a responsible factor in the transmission of malaria in March.

8. On dissection of *A. minimus* the oocyst rate which was 4·8 per cent in December was reduced to 2·0 and 2·1 per cent in January and February, but was subsequently increased to 8·6 per cent in March.

9. On dissection of *A. minimus* the sporozoite rate was 1·8 per cent in December, 0·3 per cent in January, *nil* in February and was increased to 2·6 per cent in March.

10. The main factors considered responsible for reduction in the amount of transmission of malaria during January and February when mean temperatures are below 60°F. are (*a*) the relatively short life of the vector species *A. minimus* and (*b*) the lengthened time required for the completion of the sporogony cycle.

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SOME EXPERIMENTS WITH AN AUTOMATIC MOSQUITO-CATCHING MACHINE : THE ENTORAY.

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FROM time to time there have appeared in the lay press of this country articles, sometimes illustrated, on demonstrations given by its inventor, M. Vitali Menasché, of his machine for attracting and trapping mosquitoes. On the other hand, the scientific press has been completely silent regarding the invention. When, therefore, M. Menasché offered to put his machine at the disposal of the first author for tests, it was felt that the opportunity ought to be taken advantage of, and that the apparatus should be subjected to proper scientific investigation, to see what foundation existed for the claims made in the advertising circular which was being distributed throughout the country.

As it was certain that, whatever experiments were planned, such would necessarily be of a statistical nature, the second author agreed to collaborate in the statistical analysis of the accruing data.

Ab initio, it was made perfectly clear to the inventor that in accepting his offer the authors intended to write up their findings in the form of the present paper, and that they were to be at full liberty to do so, irrespective of whether their conclusions were favourable to the machine or the reverse. The experiments were undertaken with this clear understanding, and the present authors would commence by stating that the inventor has accepted, without demur, the experimental conditions proposed, and he has not attempted to influence them to alter these even when it might have appeared, from time to time, that current results were going against his claims.

These claims were verbally modified, at the start of the experiments, in respect of the effective range of the machine. On page 3 of the inventor's circular, it is stated 'his ultra-ray machine, "Entoray", has already proved itself capable of attracting swarms of mosquitoes as well as many other species of insects within a radius of several miles'. We were, however, informed in advance that the effective range of the machine might be taken as 500 yards, and our principal experiment was planned on this figure.

As stated by the inventor in his circular, the principle of the machine is an ultra-violet ray lamp, placed at the top of a tube within which is mounted a suction turbine operated electrically. Mosquitoes and other insects attracted to the ultra-violet lamp are caught up by the fan draft and pulled into a wire gauze basket, above the fan. This basket can be closed mechanically *pari passu* with switching off the current, and the contents anæsthetised ('Cyanogas' being the agent used), sorted and counted.

No information was obtainable from the inventor as to the actual wave length of the ultra-violet ray, or to the light intensity, in foot-candles, of the visible rays given off by the lamp.

The following experiments were carried out :—

I. Does the machine attract and catch mosquitoes at all ?

II. From what distance does it attract mosquitoes ?

III. Does it catch sufficient mosquitoes to cause an appreciable reduction in density, so as to be capable either of removing or reducing mosquito nuisance or of affecting the incidence of mosquito-borne diseases ?

These three points will now be discussed separately.

EXPERIMENT I.

In February 1936, in Ballygunge, a residential area of Calcutta, with virtually uncontrolled breeding, a machine caught 18,694 mosquitoes, of both sexes, in 81 hours' working, being at the rate of 231 mosquitoes per hour. In the controlled zone at Garden Reach, in the Docks area of Calcutta, a machine working 648 hours caught 3,399 mosquitoes, of both sexes, or at the rate of 5 per hour, during February and March.

The captured mosquitoes consisted of the following 26 species :—

Species.	Number.	Percentage of catch.
Anopheles barbirostris ..	3	0·014
„ *hyrcanus* ..	19	0·088
„ *subpictus* ..	616	2·852
„ *vagus* ..	37	0·171
„ *culicifacies* ..	21	0·097
„ *fluviatilis* ..	1	0·004
„ *varuna* ..	16	0·074
„ *minimus* ..	1	0·004
„ *aconitus* ..	3	0·014
„ *stephensi* ..	1	0·004
„ *annularis* ..	2,201	10·188
„ *ramsayi* ..	30	0·139
Culex fatigans	13,851	64·116
„ *vishnui*	2,447	11·327
„ *gelidus*	141	0·652
„ *bitaeniorhynchus* ..	7	0·032
Lutzia fuscana	3	0·014
Mansonioides uniformis ..	53	0·245
„ *annuliferus* ..	4	0·018
Aëdomyia venustipes ..	2,115	9·79
Banksinella lineatopennis ..	1	0·004
Armigeres obturbans .	21	0·097
Mimomyia chamberlaini ..	6	0·027
Ficalbia hybrida	1	0·004
„ *luzonensis* ..	2	0·009
Chaoborus manilensis ..	1	0·004

The results conclusively prove that the machine does catch mosquitoes and of many, if not of all, species, whilst the numbers surely indicate some measure of attraction. It can hardly be claimed that such large numbers simply blundered within the quite weak and circumscribed range of the downdraft of the fan*, unless they were definitely attracted to the burner first. But the actual attraction distance is discussed in Experiment II.

EXPERIMENT II.

This could only be carried out by means of stained mosquitoes. Seeing that an attraction range of 500 yards was claimed, mosquitoes were released at this distance and, also, at 100 yards in case the claim was exaggerated. The experiment was conducted at the race-course at Tollygunge Club, giving the machine's rays an uninterrupted travel within the course. The mosquitoes were released at dusk, and the machine so placed that those released at 500 yards were exposed at fairly close range to the human attraction of the considerable number of members present on the lawn after the evening's golf, whilst those at 100 yards had no nearby human attraction other than the few persons near the machine itself. *C. fatigans*, bred out 24 hours previously from collected wild pupæ, was used for the experiment. The sexes could not be separately counted, but would probably average 50—50. Three thousand two hundred and ninety-two were released at 500 yards, stained with 1 per cent watery methylene

* If an insect be watched circling the burner, it is seen that it is not caught and pulled in until it is almost directly over the mouth of the fan tube. Proper portable anemometer measurements should of course be made laterally and vertically from the mouth of the tube.

blue. Three thousand three hundred and twenty were released at 100 yards, stained with 2 per cent watery eosin.

As previous work (*vide infra*) had shown clearly that the machine made its largest catches in the first two hours after dark, the machine was only worked from 6-30 p.m. to 8 p.m. Catching was continued for six nights. On the first night only males and females in abdominal stage I (Senior White, 1934) were tested for stain. On subsequent nights all specimens of the species were tested.

The results were not in favour of the claims made.

Of 240 ♂ ♂ captured and tested, one was recovered from those released at 100 yards within one hour of release.

Of 843 ♀ ♀, 6 ♀ ♀ released at 500 yards were recaptured as under :—

After	24	hours	from	release	1
„	25	„	„	„	1
„	48	„	„	„	2
„	72	„	„	„	2

making recovery percentages of 0·03 per cent at 100 yards and 0·18 per cent at 500 yards. It must be stated that, during the period of these experiments, there was a slight breeze against flight to the machine on the night of release, and wind of varying strength on subsequent nights. A very strong breeze blew for the first half hour after dark on the second night.

The inventor then requested that two factors, which he thought might prevent the expected results being obtained, should be tested :

(*a*) *That the staining was ineffective,* and that in fact many of the released mosquitoes had escaped the spray from the atomiser with which it was applied. Accordingly, to two freshly bred lots the same stains at the same concentrations were applied, though owing to the fact that the mosquitoes could not be given a final spray cloud as they left the cages, they were in fact less strongly stained than those actually released for the experiment.

The results were :—

100 stained methylene blue, 99 positive for stain.
100 stained eosin, 93 positive for stain.

This incidentally confirms the statement of Barber and Rice (1935) that methylene blue is preferable to eosin as a stain in such work.

(*b*) *That the ultra-violet ray bleached the stain on the mosquitoes.* To test this two lots of the mosquitoes used in the previous experiment, now dead, were placed in cages tied to the top of the machine, 6 inches from the burner and exposed throughout the 12 hours of darkness.

100 stained methylene blue, 97 positive for stain.
100 stained eosin, 89 positive for stain.

Neither contention, therefore, will serve to explain the very poor re-catching results, which are much lower than those recorded, after random flights over much greater distances (Senior White, 1934). It would appear, therefore, that the effective attraction range of the machine is certainly less than 100 yards.

In this connection an idea advanced by the inventor must be mentioned, though he does not make this claim in his circular. This is that the ray is lethal to mosquitoes at some feet distance in appreciable numbers. The best test for this would be to work the machine on a white sheet and see if dead

insects fell down. This was not done, but certain experiments with caged mosquitoes were made.

A. *Carried out 24th February, 1936.*
   75 ♀ newly emerged *C. fatigans* exposed for 12 hours at 41 feet. No deaths.
   60 ♀ newly emerged *C. fatigans* caged at a distance for 12 hours. No deaths (control).

B. *Carried out 26th February, 1936.*
   37 caught, fed, ♀ *C. fatigans* exposed for 12 hours at 41 feet. Thirteen deaths (35 per cent).
   18 caught, fed, ♀ *C. fatigans* caged at a distance for 12 hours. Six deaths (33 per cent) (control).

C. *Carried out 13th March, 1936.*
   A large number of newly emerged *C. fatigans* exposed for 12 hours to ray at one foot, but out of draft of fan—all dead.
   A similarly arranged cage of caught, fed, *C. fatigans,* for 12 hours—all dead.

At such close range as one foot, however, the effect of the heat emitted by the burner must be taken into consideration before any lethal action by ultra-violet rays is admitted. No measurements of this have been made. There is thus some apparent foundation for the claim, but, of course, far more careful experiments, with varying exposures, require to be done. A twelve hours' exposure at twelve inches cannot indicate anything of practical value.

EXPERIMENT III.

This is the crucial test of the machine's efficiency as a practical method of mosquito control.

Two separate experiments were made.

A.—A machine was installed at a conveniently accessible point distant from the routine check catching stations at Garden Reach situated in No. 11, No. 15 and No. 18 bungalow compounds, of 750 feet, 850 feet and 700 feet, respectively. This point fell in the middle of a railway goods yard in which one or more locomotives were shunting more or less continuously. The weekly 20-minute morning catches at these stations are on record for the past five years. To facilitate comparisons, the weeks from 1st* September, not the actual dates of the Saturday catches, are tabulated. Only figures for *C. fatigans* catches are included, as during the period of the experiment, 1st February to 31st March, this species alone is of importance in Calcutta. No alteration in the anti-larval routine work was made, and the weekly hand catching was done by the same laboratory assistants as did the work in the case of the first author's 1934 paper. Thus the trends of mosquito catches in corresponding weeks of previous years and in the present year before and after the introduction of the machine could be worked out. If these trends could be shown to have taken a significant downward turn during the period of the working of the machine a case could be made for the efficiency of the machine, provided other possible factors operating in that direction could be eliminated. The machine was operated nightly from dusk till dawn.

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* The curve for *C. fatigans* in Calcutta commences its upward rise in September (Senior White, 1934).

As a further check, against any abnormal climatic influence being at work this year, similar tabulations were made for three other routine catching stations in the Garden Reach area, situated on the western side of the protected zone, and thus remote from any possible influence of the machine. These sets of figures are given in Tables I and II. It may be taken that all mosquitoes caught have infiltrated from beyond the Garden Reach Association's protected zone. There is no actual breeding in the vicinity of the six catching stations concerned.

TABLE I.

C. fatigans *catch in Nos.* 11, 15 *and* 18 *catching stations, Garden Reach, for weeks ending Saturday, September to March* 1931–36.

Week.	*C. fatigans.*									
	1931-32.		1932-33.		1933-34		1934-35.		1935-36.	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
1		3	..	4	1	2	3	2	..	1
2	3		..	1	1	1	2	2	..	2
3	..	5	1	4	4	2	2	3	..	2
4	1	2	4	5	..	4	1	1	1	2
5	4	3	1	2	6	4	1	1	1	2
6	5	2	5	3	4	4	1	1	..	1
7	3	6	1	10	3	1	3	1	1	4
8	2	4	1	5	..	7	1	2	1	4
9	3	3	..	..	1	4	1	3	2	6
10	3	5	1	3	3	5	5	4	1	6
11	..	2	1	6	..	10	2	4	3	8
12	2	7	..	2	6	6	5	2	3	11
13	5	5	1	4	12	12	2	3	7	12
14	17	8	9	12	1	21	4	7	5	12
15	5	11	7	8	7	24	3	5	5	8
16	32	14	2	11	10	30	8	5	2	11
17	35	22	2	20	11	31	8	20	5	14
18	21	38	22	20	7	31	1	22	3	18
19	19	28	14	15	4	36	4	16	6	16
20	16	22	15	31	2	37	4	23	2	17
21	61	43	3	19	4	43	10	25	8	12
22	109	67	15	30	12	21	11	36	11	18
23	86	45	21	43	6	35	11	41	7	36
24	33	40	12	14	1	43	16	52	6	24
25	3	50	26	29	8	54	11	63	14	26
26	35	42	37	51	12	76	34	26	13	34
27	29	45	26	103	26	44	50	34	21	25
28	25	58	32	80	16	40	17	29	5	36
29	26	64	23	80	12	43	16	15	10	26
30	34	35	16	65	18	31	8	17	6	25
	617	679	298	680	198	702	245	465	149	419
	1,296		978		900		710		568	

TABLE II.

C. fatigans *catch in MacNeill, Calcutta Electric Supply and North West Soap Co. catching stations for weeks ending Monday, September to March* **1931–36.** *King George's Docks area.*

Week.	*C. fatigans.* 1931-32 ♂	1931-32 ♀	1932-33. ♂	1932-33. ♀	1933-34. ♂	1933-34. ♀	1934-35. ♂	1934-35. ♀	1935-36. ♂	1935-36. ♀
1	3	4	2	4	1	18	1	8	3	5
2	2	3	3	3	3	17	..	5	1	1
3	..	5	1	11	..	7	4	6	..	1
4	1	5	1	5	1	9	1	5	2	2
5	..	4	..	13	5	7	1	..	1	..
6	1	11	2	8	2	13	..	3	1	2
7	3	6	1	5	.	11	1	2	..	9
8	6	4	1	4	1	8	2	3	..	9
9	10	12	4	9	..	11	..	6	1	9
10	8	12	4	10	..	12	..	2	3	12
11	12	16	2	9	..	18	1	9	4	14
12	15	21	..	8	4	7	1	2	6	15
13	15	32	6	24	1	23	6	4	7	13
14	12	17	8	9	2	27	4	7	5	15
15	17	24	..	21	1	24	2	4	8	13
16	33	17	6	24	..	23	2	9	8	13
17	31	34	12	19	2	25	3	13	6	13
18	48	32	8	15	6	22	4	16	7	18
19	38	16	8	13	4	19	5	17	5	20
20	57	53	5	24	9	13	9	8	4	16
21	41	55	9	25	3	27	4	19	5	15
22	13	45	9	20	6	17	4	22	4	18
23	14	63	12	12	1	23	11	27	4	22
24	54	58	16	14	4	20	8	35	4	24
25	31	51	10	36	1	26	6	38	7	19
26	27	45	3	64	4	39	6	44	10	24
27	23	63	2	58	6	41	11	38	8	29
28	23	50	3	57	7	32	15	32	5	34
29	37	81	1	63	10	41	16	23	3	32
30	20	51	17	58	2	39	7	27	5	24
	595	890	156	645	86	619	135	434	127	441
	1,485		801		705		569		568	

Taking the second table first, the trend is evenly downwards for the first four years of control work, and shows that with the radius now controlled, no further improvement by anti-larval measures can be obtained, as the 5th year's figures are strikingly similar to those of the 4th year. In Table I, however, a steady downward trend is still apparent. The figures, however, show that this is, as between the present and the previous year, caused by a

reduction in ♂ incidence only, and that as with the western stations, covered by Table II, a ♀ incidence has apparently been produced incapable of further reduction on the present area of anti-larval treatment. This ♂ reduction does not require the action of the Entoray machine to explain it. On page 579 of the first author's 1934 paper it was shown that ♂ incidence, at No. 11 station, was a matter of importation from Shalimar, across the Hooghly. Accordingly, with further railway funds the Shalimar shore was put under permanent control from September 1934. This section of the protected area is in the young, downward trending stage of improvement, and so the ♂ infiltration into Garden Reach is to be expected to show an annual reduction for two years to come.

It may, therefore, be taken that the nightly working of the machine affected absolutely no improvement in mosquito incidence in the 250 yard radius circle (half the claimed effective distance) that covers the catching stations comprised in Table I. Mosquitoes were not attracted past these stations to the machine, so reducing the actual hand catches in the three stations, as was to be expected if the experiment was successful. This negative result follows from the results of Experiment II, done later than the initiation of Experiment III, which shows that the radius of influence of the machine is less than 100 yards.

A further confirmation of this last value was, moreover, furnished by another set of figures, relating to the first author's own flat. This is situated 250 feet—only 83 yards—mean distance from the point where the machine was operated, on a line towards the No. 11 station. For two years previously during the *C. fatigans* peak, as a measure of daily infiltration, the first author has had this flat (5 principal rooms) emptied of mosquitoes in the morning of every day on which staff could be conveniently spared to do so. But in connection with these experiments a regular daily catching was made. The results (for *C. fatigans* only—practically no other species was taken) are given in Table III, in which the *C. fatigans* catch of the Entoray machine for the corresponding date of the year is also included. Though the average daily ♀ catch is not strictly comparable owing to gaps in the first two years' records, it appears that although, throughout the period, the machine was catching *C. fatigans* ♀ ♀ at the rate of 20·5 per night, yet the average daily ♀ influx into the flat was rather higher than in the previous years. The table is given in detail, as showing the extraordinary fluctuations in the numbers caught from one night to another, which do not rise and fall *pari passu* with the influxes into the flat.

The statistical analysis is given in detail in Appendix I.

B.—The second experiment in this series was made in the residential suburb of Ballygunge, among conditions of practically uncontrolled breeding*. It had to be undertaken hurriedly when the inventor informed us that he was prepared to put a second machine at our disposal for experiment. Two

* Apart from any minor nearby breeding in gully traps and local drains, both bungalows were under the influence, at half a mile in each case, of a main outfall drain behind Ballygunge Railway Station that was producing, on 4th March, *C. fatigans* at the rate of 18,200 larvæ and pupæ in 6 dips of a ladle holding 150 c.c. or 20·2 larvæ and pupæ per c.c. of surface water. It was not until 20th March that the Calcutta Corporation treated this breeding place. This treatment thus hardly affects the experiment.

catching stations were chosen, one in the third author's bungalow, and one in the bungalow of Capt. Chalam, Malariologist, E. B. Railway. Both were servants' rooms, similar to those used as catching stations in Garden Reach area. The bungalows are approximately half a mile apart in a straight line. Dr. Adhikari's bungalow was used for the experiment, Capt. Chalam's for the control. No previous records for either were available, and thus to institute comparisons, the machine was removed at the end of February, and hand catching continued throughout March to indicate comparable values without the machine, which was operated, except on the first 3 nights, for 4 hours from dusk, and on 12 nights for the last two hours before dawn also.

TABLE III.

Adult catches. C. fatigans.

5, *Godfrey Mansions—Whole flat emptied.*

**Entoray each night from 1st February,* 1936.

Date.	1934		1935		1936		Entoray—12 hours' catch.		REMARKS.
	♂	♀	♂	♀	♂	♀	♂	♀	
February.									
1st	..	..	..	..	4	3	*	..	
2nd	..	..	..	..	0	5	0	21	
3rd	..	..	..	..	3	4	7	33	
4th	..	..	..	..	1	5	..	..	No Ray run.
5th	..	..	..	..	0	6	2	7	
6th	..	..	..	..	2	4	2	5	
7th	..	..	..	..	4	12	0	2	
8th	0	2	..	..	2	10	4	6	
9th	1	0	..	..	4	8	0	1	Heavy rain—8th.
10th	1	3	..	..	3	6	2	21	
11th	..	..	3	8	4	1	2	11	
12th	0	4	13	33	3	4	0	6	
13th	0	2	13	20	1	5	7	26	
14th	1	0	7	23	2	0	6	16	
15th	0	1	3	17	0	2	..	?	Catch all wet. Unsortable.
16th	0	2	..	..	1	2	0	10	
17th	..	..	..	..	1	3	..	?	Catch wet. Biting bad at night
18th	..	..	5	8	2	3	7	28	Biting not bad.
19th	1	5	8	5	2	5	20	19	
20th	..	..	8	4	2	5	57	75	
21st	..	..	6	4	4	5	20	23	Machine failure (? time).
22nd	0	6	3	9	3	9	40	100	
23rd	..	..	2	7	9	16	35	7	
24th	0	3	4	4	9	23	9	14	
25th	..	..	5	6	9	15	4	6	
26th	..	..	12	8	6	13	9	26	
27th	..	..	7	7	8	17	4	12	
28th	..	..	5	4	4	13	2	14	
29th	..	..	..	..	1	2	9	34	

TABLE III—*concld.*

Date.	1934		1935		1936		Entoray—12 hours' catch.		REMARKS.
	♂	♀	♂	♀	♂	♀	♂	♀	
					March.				
1st	4	14	4	8	11	2	5	18	
2nd	0	10	6	4	3	6	63	54	
3rd	2	8	*2	8	10	5	54	71	* Incomplete catch.
4th	1	14	4	4	5	14	52	28	
5th	0	8	..	..	4	12	20	72	
6th	0	12	6	3	4	10	3	16	
7th	0	7	2	4	3	6	5	32	
8th	3	6	3	4	6	9	12	14	
9th	0	10	3	3	3	12	3	17	
10th	3	3	7	4	2	11	7	23	
11th	..	..	6	2	3	6	7	30	
12th	2	7	5	2	3	4	3	10	
13th	3	3	4	6	3	3	3	23	
14th	1	0	1	1	3	2	1	5	
15th	1	3	3	2	2	7	0	8	
16th	2	1	0	1	2	4	7	13	
17th	0	2	1	2	1	3	0	4	
18th	..	..	..	..	2	4	0	2	
19th	2	2	0	0	2	2	2	11	
20th	2	6	0	1	1	3	2	6	
21st	2	3	0	0	2	5	0	*1	* Failed in ½ hour.
22nd	0	4	0	2	3	8	0	15	
23rd	..	..	2	1	0	3	..	*	* Failure complete. Fuse blown.
24th	0	0	..	..	1	1	6	0	
25th	..	..	1	1	0	3	2	11	
26th	..	..	0	1	0	1	3	15	
27th	..	..	1	1	0	3	2	5	
28th	..	..	0	2	1	1	3	6	
29th	..	..	0	0	1	4	9	25	
30th	..	..	1	0	0	0	7	30	
31st	..	..	..	..	0	1	..	..	
	32	151	166	234	175	361	529	1,088	
	32 days		43 days		60 days		53 days		= 636 hours.
♀ per catch	4·7		5·4		6·0		20·5		

The statistical analysis is given in detail in Appendix II. From this it appears that though there is a significant reduction in ♀ incidence in favour of the machine, this is not so in regard to ♂ incidence, and it would appear that some other unknown factor has affected these results, and that no beneficial action can be attributed to the machine's action.

Whilst the practical results achieved with the machine cannot be said to be at all encouraging, an analysis of the catches made affords data that

throw quite a new light on several aspects of mosquito bionomics, and make it quite certain that as an instrument of research the machine has a very distinct future.

From Tables I to III (Senior White, 1934), and similar, unpublished records for subsequent years, the culicid fauna of Garden Reach during the months of February and March is as given in Table V.

On the evidence of the catching stations, the number of individual species occurring in this area is continually decreasing, with a corresponding rise in the percentage prevalence of *C. fatigans.* That this result is not the real state of affairs, the Entoray catch record for the two months' period of 1936 definitely brings out. This shows that *C. fatigans*, instead of being almost cent per cent of the mosquito population, is, in reality, little more than half of it. There is nearly as numerous *A. annularis* population which is not resting by day in houses, and the presence of which would by ordinary methods have remained quite unsuspected. *Aëd. venustipes* is seen to be present in some numbers, whereas five years' house catching has produced

TABLE IV.

Entoray experiment—February and March 1936.

C. fatigans *only.*

Date.	(Control) Chalam 20 min.		Experiment Adhikari 20 min.		'Entoray' night.		REMARKS.
	♂	♀	♂	♀	♂	♀	
				February.			
							Ray run.
6th	25	22	30	31	298	261	2 hours.
7th	26	34	46	40	117	341	2 ,,
8th	10	69	38	44	44	38	½ hour.
9th	20	65	9	28	374	488	4 hours.
10th	2	104	24	28	301	239	4 ,,
11th	6	111	17	41	557	477	4 ,,
12th	4	124	9	44	352	297	4 ,,
13th	7	112	9	59	369	356	4 ,,
14th	8	73	10	32	198	341	4 ,,
15th	9	34	11	21	282	415	4 ,,
16th	23	103	16	22	290	408	4 ,,
17th	3	96	19	13	156	275	6 ,, strong breeze.
18th	1	99	36	21	436	365	6 hours.
19th	7	97	44	33	329	364	5 ,,
20th	5	43	14	12	247	323	6 ,,
21st	8	49	16	14	366	462	6 ,,
22nd	7	103	16	13	345	593	6 ,,
23rd	10	92	16	24	268	320	6 ,,
24th	36	83	13	22	278	409	6 ,,
25th	7	56	4	11	610	670	6 ,,
26th	10	61	13	8	577	843	6 ,,
27th	17	102	11	18	232	361	6 ,,
28th	10	51	11	9	560	848	6 ,,
29th	33	70	25	21	550	782	6 ,,

TABLE IV—*concld.*

Date.	(Control) Chalam 20 min. ♂	(Control) Chalam 20 min. ♀	Experiment Adhikari 20 min. ♂	Experiment Adhikari 20 min. ♀	'Entoray' night. ♂	'Entoray' night. ♀	REMARKS.
			March.				
1st	26	71	11	14	..	..	Ray stopped.
2nd	47	46	15	15	..	..	
3rd	21	32	8	22	..	..	
4th	79	80	18	48	..	..	
5th	76	79	43	65	..	..	
6th	97	97	62	50	..	..	
7th	84	68	44	48	..	..	
8th	78	85	48	57	..	..	
9th	72	92	45	49	..	..	
10th	32	45	12	23	..	..	
11th	2 (flit)	2	13	25	..	..	
12th	12	15	10	14	..	..	
13th	1	9	14	22	..	..	
14th	1	19	12	14	..	..	
15th	5	12	17	12	..	..	
16th	3	3	3	7	..	..	
17th	7	9	14	18	..	..	
18th	1	3	8	7	..	..	
19th	1	5	5	7	..	..	
20th	3	1	11	17	..	..	
21st	4	2	20	10	..	..	
22nd	4	1	13	12	..	..	
23rd	3	1	5	5	..	..	
24th	1	0	7	11	..	..	
25th	2	5	13	3	..	..	
26th	2	12	11	18	..	..	
27th	4	6	10	14	..	..	
28th	1	2	0	5	..	..	
29th	0	6	2	12	..	..	
30th	3	9	4	9	..	..	
31st	3	4	8	15	..	..	
	969	2,674	1,005	1,410	7,936	10,276	113¾ hours.
	55 days		55 days		69 8	90·3	per hour.
Average	17 6	48 6	18 2	25·6			
			457	610			24 days with Ray working.
			24 days				
			19·1	25·4			

TABLE V.

Species.	1932		1933		1934		1935		1936		Entoray catch. 1936	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
A. fluviatilis ..	..	..	..	..	..	..	..	..	..	..	0	1 *
A. varuna ..	3	3	1	0	1	0	..	..	..	..	0	2
A. minimus ..	..	..	0	1	..	..	..	..	..	..	..	..
A. aconitus ..	..	..	0	3	..	..	..	..	..	..	..	..
A. culicifacies ..	..	..	..	..	..	..	..	..	..	..	0	1 *
A. subpictus ..	3	1	2	2	5	2	..	..	1	2	8	40
A. vagus ..	..	..	1	0	2	3	0	2	..	..	0	3
A. stephensi ..	0	1	..	..	..	..	..	..	..	..	0	1
A. annularis ..	0	1	1	0	1	1	0	2	..	..	117	918
A. hyrcanus ..	..	..	1	0	..	..	..	..	..	..	0	1
C. fatigans ..	672	1,293	337	1,152	237	1,025	332	1,001	240	852	547	1,137
C. vishnui ..	6	18	2	8	7	10	..	..	..	..	4	39
C. tritaeniorhynchus .	0	1	4	6	0	1	5	9	..	..	..	..
C. gelidus ..	0	5	..	..	..	..	..	..	..	..	0	1
C. bitaeniorhynchus ..	3	3	1	4	0	1	2	0	..	..	..	..
L. fuscana ..	0	1	..	..	..	..	..	..	..	..	1	0
S. fasciata ..	2	4	0	3	..	..	..	..	..	..	..	..
M. annuliferus ..	..	..	1	1	..	..	..	..	..	..	..	..
Ar. obturbans ..	0	1	0	1	.	.	..	..	..	..	..	..
Aed. venustipes ..	..	..	..	..	..	..	..	..	..	..	7	67 *
M. chamberlaini ..	..	..	..	..	..	..	..	..	..	..	1	0 *
F. hybrida ..	..	..	..	..	..	..	..	..	..	..	0	1 *
No. of species ..	13		14		8		5		2		15	
Per cent *C. fatigans* ..	97 2		97 2		97 4		98 5		99 7		54 8	

only three specimens of this species. Species which have never appeared in house catches in this area in these two months are indicated in the Entoray catch column by an asterisk. The refinding of *M. chamberlaini*, not found in the area since Iyengar recorded it in 1920 (Senior White, 1934), is interesting. Even more so is the record of a single *A. fluviatilis*, which Covell considered as unlikely to occur in Calcutta (Senior White, 1934), which is now confirmed by an undoubted ♀ specimen, confirmed as such by the Malaria Survey of India.

The records of the Ballygunge experiment are even more instructive, as in this case the collecting basket was cleared every hour from dusk (about 6 p.m.) to 10 p.m., and the machine was re-started at 4 to 4-30 a.m. and the basket emptied in the penultimate and last hours before dawn. It is thus possible to obtain some idea of the movements of various species, over the whole period of darkness, hour by hour. The work of Timbres (1935) has shown how important this is in regard to the movements and prevalence in houses of *A. philippinensis*, the principal carrier of the area he studied.

The totalled results are given in Table VI.

Table VI.

'Entoray'.

Hourly catches—25, Hindustan Park.

16th to 29th February.

Actual catches.

Species.	18·00–19·00		19·00–20·00		20·00–21·00		21·00–22·00		4 hrs. total.		4·00–5·00		5·00–6·00		2 hrs. total.	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
A. barbirostris ..	0	1	0	1	0	1	..	..	0	3	..	..	..	..	..	..
A. hyrcanus ..	4	10	0	2	..	..	..	..	4	12	0	2	..	..	0	2
A. varuna ..	0	8	0	3	..	..	1	2	1	13	..	..	..	..	..	..
A. minimus ..	0	1	..	..	..	..	..	..	0	1	..	..	..	..	..	..
A. aconitus ..	0	3	..	..	..	..	..	..	0	3	..	..	..	..	..	..
A. culicifacies ..	0	8	1	7	0	3	0	1	1	19	..	..	..	..	..	..
A. subpictus ..	97	287	30	64	8	34	6	18	141	403	2	6	9	7	11	13
A. vagus ..	0	20	0	4	0	4	0	2	0	30	0	3	0	1	0	4
A. annularis ..	92	562	18	206	13	130	16	64	139	962	4	25	11	15	15	40
A. ramsayi ..	0	17	0	9	0	4	..	..	0	30	..	..	..	..	..	..
C. fatigans ..	3,329	4,317	746	1,155	407	565	276	518	4,758	6,555	74	137	312	331	386	468
C. vishnui ..	278	991	100	427	51	197	51	162	480	1,777	25	74	16	32	41	106
C. gelidus ..	32	35	11	16	10	11	3	7	56	69	2	10	3	0	5	10
C. bitaeniorhynchus ..	1	4	0	1	..	..	..	..	1	5	..	..	1	0	1	0
L. fuscana ..	1	1	..	..	..	..	..	..	1	1	..	..	..	..	..	..
M. uniformis ..	6	19	0	8	1	6	3	9	10	42	0	1	..	..	0	1
M. annuliferus ..	0	3	..	..	..	..	..	..	0	3	0	1	..	..	0	1
Aëd. venustipes ..	93	1,109	15	293	8	176	4	169	120	1,747	2	104	9	59	11	163
B. lineatopennis ..	..	..	0	1	..	..	..	..	0	1	..	..	..	..	..	..
Ar. obturbans ..	3	5	1	2	1	0	..	..	5	7	1	2	3	3	4	5
Mim. chamberlaini ..	0	3	0	2	..	..	..	..	0	5	..	..	..	..	..	..
F. luzonensis ..	1	0	..	..	0	1	..	..	1	1	..	..	..	..	..	..
Total ..	3,937	7,404	922	2,201	499	1,132	360	952	5,718	11,689	110	365	364	448	474	813

TABLE VI—*contd.*

Species.	Average per hour catch.															
	18·00–19·00		19·00–20·00		20·00–21·00		21·00–22·00		4 hrs. avge.		4·00–5·00		5·00–6·00		2 hrs. avge.	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
A. barbirostris ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
A. hyrcanus ..	..	..	..	..	..	..	..	..	0	1	..	..	..	..	..	..
A. varuna ..	..	..	..	..	..	..	..	..	0	1	..	..	..	..	..	..
A. minimus ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
A. aconitus ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
A. culicifacies ..	..	..	..	..	..	..	..	..	0	1	..	..	..	..	..	..
A. subpictus ..	7	20	2	5	1	2	0	1	10	29	..	..	..	..	..	..
A. vagus ..	0	1	..	..	..	..	..	..	0	2	..	..	..	..	..	..
A. annularis ..	7	40	1	15	1	9	1	5	10	69	0	2	1	1	1	4
A. ramsayi ..	0	1	..	..	..	..	..	..	0	2	..	..	..	..	..	..
C. fatigans ..	238	308	53	82	29	40	20	37	339	468	6	11	24	26	31	38
C. vishnui ..	20	71	7	30	4	14	4	12	34	127	2	6	1	2	·4	8
C. gelidus ..	2	·2	1	1	..	..	..	..	4	5	..	..	..	..	..	..
C. bitaeniorhynchus ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
L fuscana ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
M. uniformis .	0	1	..	..	..	..	..	..	0	3	..	..	..	..	..	..
M. annuliferus ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Aëd. venustipes ..	7	79	1	21	0	13	0	12	9	125	0	9	0	5	0	13
B. lineatopennis ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Ar. obturbans ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Mim. chamberlaini ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
F. luzonensis ..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

TABLE VI—*concld.*

Species.	Percentage catch per hour.											
	18·00–19·00		19·00–20·00		20·00–21·00		21·00–22·00		4·00–5·00		5·00–6·00	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
A. barbirostris ..	..	..	..	..	..	..	..	..	..	..	..	..
A. hyrcanus ..	..	..	..	..	..	..	..	..	..	..	..	..
A. varuna ..	..	..	..	..	..	..	..	..	..	..	..	..
A. minimus ..	..		..	..	..	..	..	..	..	..	..	..
A. aconitus ..	..	..	..	..	.	..	..	..	..	..	..	..
A. culicifacies ..	..	..	..	..	..	..	..	..	..	..	..	..
A. subpictus ..	64	68	20	15	5	8	4	4	1	1	6	2
A. vagus ..	..	..	..	..	..	..	..	..	..	..	..	..
A. annularis ..	63	55	12	20	8	13	10	6	2	3	7	2
A. ramsayi ..	..	..	..	..	..	..	..	..	..	..	..	..
C. fatigans ..	65	61	15	16	8	8	5	7	1	2	7	5
C. vishnui ..	53	53	19	23	10	10	10	9	5	4	3	1
C. gelidus ..	..	..	..	..	..	..	..	..	..	..	..	..
C. bitaeniorhynchus ..	..	.	..	..	..	..	..	..	..	..	..	..
L. fuscana ..	..	..	..	..	..	..	..	..	..	..	..	..
M. uniformis ..	..	..	..	..	..	..	..	..	..	..	..	..
M. annuliferus ..	..	..	..	..	..	..	..	..	..	..	..	..
Aëd. venustipes ..	71	57	11	15	6	9	3	9	1	5	7	3
B. lineatopennis ..	..	..	..	..	..	..	..	..	..	..	..	..
Ar. obturbans ..	..	..	..	..	..	..	..	..	..	..	..	..
Mim. chamberlaini ..	..	..	..	..	..	..	..	..	..	..	..	..
F. luzonensis ..	..	..	..	..	..	..	..	..	..	..	..	..

The first point to notice is the very large number of species, twenty-two, that are on the wing in an uncontrolled area, even in so unproductive a month (from the point of view of number of species) as February. During the same period the morning hand catch had produced, in addition to *C. fatigans*, only small numbers of *C. vishnui*, *L. fuscana*, *A. subpictus*, and *A. vagus*. No indication whatever would have been obtained of the really large numbers of *A. annularis* and *Aëd. venustipes* that were actually on the wing.

The second point of interest—it is really one of very great importance—is that every species encountered in sufficient numbers to make a per hour average possible, is in maximum movement in the first hour of darkness. Some species gradually decrease up to 10 p.m., others are as active in the fourth as in the third hour from dusk. No records are available from 10 p.m. to 4 a.m., and these will undoubtedly have to be made to complete the activity picture, but at 4 a.m. we see minimal movement, increasing, however, as dawn approaches and (presumably) daylight resting places are sought out. Such records, and the knowledge that will accrue from them, cannot fail to have an important bearing on our knowledge of the transmission of mosquito-borne diseases. If a machine were placed in a room it would yield information regarding ingress and egress, to compare with movements in the open.

This table also shows very great differences in the proportions of the sexes caught in different species, from 42 per cent of ♂ in *C. fatigans* to only 6 per cent in *Aëd. venustipes*. This may mean that the attraction of the ultra-violet rays for different species varies, or it may mean that in species like the latter the males stay close to the point of emergence, and so would indicate interesting specific difference in habits and flight powers.

Senior White (1934) stated that the total mosquito fauna of Calcutta stands at 47 species. This must now be increased to fifty, by the following records obtained since that paper was published: *Uranotaenia orientalis* Barr., caught in Garden Reach on 13th November, 1934, *Banksinella lineatopennis* Ludl., caught on a railway ferry steamer on 4th February, 1935, and again in the course of the present work in Ballygunge on 19th February, 1936, and *A. fluviatilis* James, caught in the course of the present work at Garden Reach on 19th February, 1936.

It is of course not to be expected that the whole of this total would be caught in the two winter months of the present experiments. But the proportion of species caught is important as having a bearing on whether, as claimed, this machine attracts all species of mosquitoes or whether certain species are not attracted by the rays. In this respect, the most noticeable absentee is *Stegomyia fasciata* Fb. (*Aëd. aegypti* L.). Admittedly February and March are not months of maximal incidence for this species, but it is indeed extraordinary that out of so large a total of species and of specimens, not a single specimen of this species should have been taken. Certainly at Garden Reach it has been reduced practically to vanishing point (in 1935-36 only 2 specimens were taken in the 12 catching stations in the whole 12 months), but this can hardly be the case elsewhere in the city. Again, it is really extraordinary that the domestic breeding *A. stephensi* should be represented in the catches by one single specimen only, and that one from Garden Reach, where all the overhead cisterns within claimed range of the machine have now been mosquito-proofed; and that in Ballygunge, with many old unproofed cisterns,

this species was not obtained at all. In our opinion it is a matter of extreme urgency from the point of view of the machine as a practical proposition that these points should be elucidated as early as possible, for its value will be greatly lessened if these two species prove to be refractory to the attraction of the rays. The present experiments must be taken to be merely preliminary, and only open out vistas of years of work ahead, calling for the co-operation of the physicist with the entomologist. Enough, however, has, we think, emerged from the present short series of experiments to indicate that the machine deserves to be taken seriously, if not yet as an instrument of control, at least as an instrument of research. At the first writer's suggestion the inventor is now engaged on modifying the construction of the chimney tube of the machine so that

(*a*) the larger insects attracted, moths, butterflies and crickets, are excluded from the catch, on the lines of the automatic catching apparatus described by Mulhem (1934).

(*b*) Mosquitoes, and other insects of like size, are received into modified Barraud boxes, moved automatically at pre-regulated intervals into and out of the air-sweep, on the lines described by Williams (1935). By this means it is hoped to conserve the mosquitoes captured alive and in better condition until morning, rendering the rarities fit for pinning, and those species of medical importance useful for dissection and origin of blood meal work. By this means it is expected that the investigation, qualitative and quantitative, of the mosquito fauna of an area under survey, and the obtaining in numbers for dissection of suspected carrier species will be greatly facilitated.

APPENDIX I.

STATISTICAL ANALYSIS OF THE FIGURES RELATING TO EXPERIMENTS WITH 'ENTORAY' MACHINE.

GARDEN REACH AREA.

Regarding the experimental centres at Garden Reach the factors tending to reduce mosquito nuisance are :—

1. The seasonal anti-larval measures at Shalimar up to 1934. In the beginning (i.e., for the period 8th December, 1931, to 10th May, 1932) only a small area round the ferry pontoons was oiled but in subsequent years the control at Shalimar was put over a more extensive area.

2. Perennial anti-larval measures during 1935. This factor could influence the mosquito larvæ in 1935-36 only.

The factors which have been favourable are :—

1. Deficient rainfall in November months of the last four years. It is stated that higher the rainfall during this month the lesser the mosquito nuisance. The 1935-36 period has been particularly deficient in rainfall.

2. Infiltration of mosquitoes from the south due to discontinuance of the Corporation anti-mosquito work.

The question is whether these factors are enough to explain the significance of divergence, if any, between the 1935-36 experience and the one expected on

the basis of the past years' figures, or whether some other factor must be taken into account, viz., the machine. The machine was brought into operation only after the 22nd week, i.e., from 1st September.

Altogether the following factors may be considered to have affected the 1935-36 figures only :—

(*a*) Abnormal deficiency of rainfall during November 1935.

(*b*) Increased infiltration of mosquitoes from the south.

(*c*) Perennial anti-larval measures at Shalimar.

(*d*) A secular trend, if any, which would include all other factors during the previous years.

(*e*) The machine affecting only from 23rd to 30th week.

COMPARISONS OF THE ACTUAL CATCHES WITH THE EXPECTED.

(A) We first calculate what the weekly catches in 1935-36 would have been if all the other factors not included in the secular trend were absent. This can be taken to be the normal experience for 1935-36 as judged by the past experience. This is done by fitting 30 straight line trends to the 30 sets of weekly catches, each set including the catches in a particular week for all the years. The figures are considered separately for males and for females. Table VII gives in column 4 the expected values for females for 1935-36 when the straight lines have been fitted.

In column 2 is given the mean experience of corresponding weeks of 1931–34. 'b' in column 3 gives half the increase ( ) or decrease (—) which the weekly catches suffer per year. Deviations from the expected experience are set out in column 6; negative deviation meaning that the actual experience was more than what was expected. The deviations from 23rd week onward relate to the machine period. Mean deviation in the pre-machine period is +0·90 while in the machine period it is —3·25 or in other words the actual experience which was lower than the expected in the first 22 weeks increased and became greater than the expected during the machine period. Let us now test the significance of the difference of the mean deviations during the two periods. The pooled estimate of standard deviation is 7·56

$$t = \frac{-3{\cdot}25 - 0{\cdot}90}{7{\cdot}56\sqrt{\frac{1}{22} + \frac{1}{8}}} = -1{\cdot}33$$

which gives P lying between 0·20 and 0·17 and shows no significance.

This adverse effect during the machine period can therefore be explained as being purely due to random fluctuations. If the assumption that the effects of factors (*a*) to (*d*) in 1935-36 have been the same throughout the 30-week period is right, the machine has failed to bring about any reduction in female mosquito catches.

Actually the catches in 1935-36 had begun to show a decrease as compared to the expected nine weeks previous to the installation of the machine. This means that some factors were operative reducing the mosquito incidence before the machine was introduced and the assumption may be made that these factors continued to operate during the first few weeks when the machine was

Table VII.

Females—Experimental area. Comparison of the actual experience of **1935-36** *with the expected calculated on the basis of weekly trends.*

1	2	3	4	5	6
Week.	Mean experience, 1931–34.	(*b*).	Expected for 1935–36.	Actual experience, 1935–36.	Deviations, expected *minus* actual.
1	2·75	—0·25	1·50	1	0·50
2	1·00	0·30	2 50	2	0·50
3	3·50	—0 40	1·50	2	—0·50
4	3·00	—0·20	2·00	2	0·00
5	2·50	—0·20	1·50	2	—0·50
6	2·50	—0·10	2·00	1	1·00
7	4·50	—1·20	...	4	—4·00
8	4·50	—0·20	3·50	4	—0·50
9	2·50	0·20	3·50	6	—2·50
10	4·25	—0·05	4·00	6	—2·00
11	5·50	0·50	8·00	8	0·00
12	4·25	—0·70	0·75	11	—10·25
13	6·00	0·10	6·50	12	—5·50
14	12·00	0·30	13·50	12	1·50
15	12·00	—0·10	11·50	8	3·50
16	15·00	—0·40	13·00	11	2·00
17	23·25	0·25	24·50	14	10·50
18	27·75	—1·85	18·50	18	0·50
19	23·75	—0·75	20·00	16	4·00
20	28·25	0·45	30·50	17	13·50
21	32·50	—1·50	25·00	12	13·00
22	38·50	—5·10	13·00	18	—5·00
23	41·00	—1·00	36·00	36	0·00
24	37·25	3·25	21·00	24	—3·00
25	49·00	3·20	33·00	26	7·00
26	48·75	—1·15	43·00	34	9·00
27	56·50	—4·60	33·50	25	8·50
28	51·75	—6·35	20·00	36	—16·00
29	50·50	—9·20	4·50	26	—21·50
30	37·00	—4·40	15·00	25	—10·00

installed but later some other factors came in which reversed the position and the machine did not succeed in counterbalancing their effect. Was this factor, the increased infiltration from the south ?

Table VIII sets out the same information for male catches in the experimental area.

The expected curve of weekly catches in some cases gives negative values. In such cases zeroes have been taken for purposes of comparison with the actual curve. Here the mean deviation changes from —1·32 to —0·94. The difference is insignificant as shown below :—Pooled estimate of the variance = 21·55

$$t = \frac{-1{\cdot}32 + 0{\cdot}94}{4{\cdot}64\sqrt{\frac{1}{22} + \frac{1}{8}}} = \frac{-0{\cdot}38}{1{\cdot}92} = -\,0{\cdot}20.$$

TABLE VIII.

Males—Experimental area. Comparison of the actual experience **1935-36** *with the expected calculated on the basis of weekly trends.*

1	2	3	4	5	6
Week.	Mean experience.	(*b*).	Expected for 1935–36.	Actual experience.*	Deviations, expected *minus* actual.
1	1·00	0·50	3·50	..	3·50
2	1·50	—0·10	1·00	..	1·00
3	1·75	0·45	4·00	..	4·00
4	1·50	—0·20	0·50	1	—0·50
5	3·00	—0·20	2·00	1	1·00
6	3·75	—0·65	0·50	..	0·50
7	2·50	0·10	3·00	1	2·00
8	1·00	—0·20	..	1	—1·00
9	1·25	—0·25	..	2	—2·00
10	3·00	0·40	5·00	1	4·00
11	0·75	0·25	2·00	3	—1·00
12	3·25	0·75	7·00	3	4·00
13	5·00	0·10	5 50	7	—1·50
14	7·75	—2·35	..	5	—5·00
15	5·50	—0·30	4·00	5	—1·00
16	13·00	—3·20	..	2	—2·00
17	14·00	—3·60	..	5	—5·00
18	12·75	—3·75	..	3	—3·00
19	10·25	—2·75	..	6	—6·00
20	9·25	—2·45	..	2	—2·00
21	19·50	—7·60	..	8	—8·00
22	36·75	—14 85	..	11	—11·00
23	31·00	—12·00	..	7	—7·00
24	15·50	—3·10	..	6	—6·00
25	12·00	0 30	13·50	14	—0·50
26	29·50	—1·40	22·50	13	9·50
27	32·75	3 15	17 00	21	—4·00
28	22·50	—2·00	12·50	5	7·50
29	19·25	—2·05	9·00	10	—1·00
30	19·00	3·80	..	6	—6·00

Thus according to this test the machine has caused no reduction in male mosquito catches also.

We know that the anti-larval measures at Shalimar in 1931 were confined to a smaller area as compared to the area which was covered in subsequent years. This is brought out by a considerable fall in the case of male weekly catches curve after 1931. The female experience as expected was not materially affected by these measures. Another test similar to the two above was therefore carried out for males by excluding the 1931 experience. This treatment becomes necessary on account of the negative values in column 4 as mentioned above.

TABLE IX.

Males—Experimental area. Comparison of the actual experience 1935-36 *with the expected calculated on the basis of weekly trends.*
(The 1931 experience has been excluded.)

1	2	3	4	5	6
Number.	Mean experience.	(2*b*).	Expected for 1935–36.	Actual.	Deviations, expected *minus* actual.
1	1·3	1·5	4·3	..	4·3
2	1·0	1·0	3·0	..	3·0
3	2·3	0·5	3·3	..	3·3
4	1·7	—1·5	..	1·0	—1·0
5	2·7	..	2·7	1·0	1·7
6	3·3	—2·0	..	..	..
7	2·3	1·0	4·3	1·0	3·3
8	0·7	..	0·7	1·0	—0·3
9	0·7	0·5	1·7	2·0	—0·3
10	3·0	2·0	7·0	1·0	6·0
11	1·0	0·5	2·0	3·0	—1·0
12	3·7	2·5	8·7	3·0	5·7
13	5·0	0·5	6·0	7·0	—1·0
14	4·7	—2·5	..	5·0	—5·0
15	5·7	—2·0	1·7	5·0	—3·3
16	6·7	-3·0	0·7	2·0	—1·3
17	7·0	3·0	13·0	5·0	8·0
18	10·0	—10·5	..	3·0	—3·0
19	7·3	—5·0	..	6·0	—6·0
20	7·0	—5·5	..	2·0	—2·0
21	5·7	3·5	12·7	8·0	4·7
22	12·7	—2·0	8·7	11·0	—2·3
23	12·7	—5·0	2·7	7·0	—4·3
24	9·7	2·0	13·7	6·0	7·7
25	15·0	—7·5	..	14·0	—14·0
26	27·7	—1·5	24·7	13·0	11·7
27	34·0	12·0	58·0	21·0	37·0
28	21·7	—7·5	6·7	5·0	1·7
29	17·0	—3·5	10·0	10·0	..
30	14·0	—4·0	6·0	6·0	..

The mean deviation for the first 22 weeks is + 0·61 and during the period under machine effect it is + 4·98. Let us test the significance of the difference of these two mean deviations. Pooled estimate of standard deviation is 8·19

$$t = \frac{4{\cdot}98 - 0{\cdot}61}{8{\cdot}19\sqrt{\frac{1}{22} + \frac{1}{8}}} = 1{\cdot}29$$ which gives P between 0·20 and 0·24.

Therefore by excluding the 1931 experience also no significant reduction is brought out by the machine.

We might, therefore, conclude that on the basis of weekly trends only, the machine fails to occasion any significant difference in mosquito catches whether due to infiltration from a distance (females) or to breeding near by (males).

(B) In the above tests we have assumed that factors (*a*) to (*d*) were the only factors of importance operating in 1935-36 and that they exerted uniform influence throughout the period. It may just as well be that another set of unknown factors such as sudden climatic changes, etc., came in during the period the machine was working and thus counterbalanced its effect. If we suppose that these factors affected equally the experimental area at Garden Reach and the control at King George's Docks then their existence can be tested by seeing if at the latter place 1935-36 experience as compared with an average experience of the previous years was different in the two periods, viz., the pre-machine and the machine period.

TABLE X.

Females—Control area. Comparison of the actual 1935-36 *weekly catches with the average of the period* 1931–34.

1	2	3	4
Number.	Average.	1935 actual	Deviations, average *minus* actual.
1	8·5	5	3·5
2	6·8	1	5·8
3	7 3	1	6·3
4	6·0	2	4·0
5	6·0	..	6·0
6	8·8	2	6·8
7	6·0	9	—3·0
8	4·8	9	—4·2
9	9·5	9	—0·5
10	9·0	12	—3·0
11	13 0	14	—1·0
12	9·5	15	—5·5
13	20·8	13	7·8
14	15·0	15	..
15	18·3	13	5·3
16	18·3	13	5·3
17	22·8	13	9·8
18	21·3	18	3·3
19	16·3	20	—3·7
20	24·5	16	8·5
21	31·5	15	16·5
22	26·0	18	8·0
23	31·3	22	9·3
24	31·8	24	7·8
25	37·8	19	18·8
26	48·0	24	24·0
27	50·0	29	21·0
28	42·8	34	8·8
29	52·0	32	20·0
30	43·8	24	19·8

In columns 2 and 3 are given the average weekly experience of the past four years and the actual 1935-36 experience respectively. Deviations are given with proper sign in column 4.

Mean deviation 1—22 weeks = 3·45.

Mean deviation 23—30 weeks = 16·18.

$$t = \frac{16{\cdot}18 - 3{\cdot}45}{5{\cdot}75\sqrt{\frac{1}{22} + \frac{1}{8}}} = \frac{12{\cdot}73}{2{\cdot}36} = 5{\cdot}39 \text{ which is highly significant.}$$

This shows that in the control area the mosquito incidence in 1935-36 was significantly lower in the machine period as compared with the pre-machine period taking into consideration the experience of the previous four years. The same is true in the case of males as is brought out by the following analysis :—

TABLE XI.

Males—Control area. Comparison of the actual 1935-36 *weekly catches with the average of the period* 1931–34.

1	2	3	4
Number.	Average.	Actual 1935.	Deviations, average *minus* actual.
1	2·0	3	—1·0
2	2·0	1	1·0
3	1·3	..	1·3
4	1·0	2	—1·0
5	1·5	1	0·5
6	1·3	1	0·3
7	1·3	..	1·3
8	2·5	..	2·5
9	3·5	1	2·5
10	3·0	3	..
11	3·8	4	—0·2
12	5·0	6	—1·0
13	7·0	7	..
14	6·5	5	1·5
15	5·0	8	—3·0
16	10·5	8	2·5
17	12·0	6	6·0
18	16·5	7	9·5
19	13·8	5	8·8
20	20·0	4	16·0
21	14·3	5	9·3
22	8·0	4	4·0
23	9·5	4	5·5
24	20·5	4	16·5
25	12·0	7	5·0
26	10·0	10	..
27	10·3	8	2·3
28	12·0	5	7·0
29	16·0	3	13·0
30	11·5	5	6·5

Mean deviation 1—22 weeks $= \frac{60.8}{22} = 2.76$.

Mean deviation 23—30 weeks $= \frac{55.8}{8} = 6.97$.

$$t = \frac{6.97 - 2.76}{4.77\sqrt{\frac{1}{22} + \frac{1}{8}}} = \frac{4.21}{1.96} = 2.15 \text{ which also is significant.}$$

We thus see that in the experience of King George's Docks the deviation curve (expected minus actual) significantly rises during the machine period, i.e., some factors were operative here during this period which militated against the mosquito incidence. In the case of Garden Reach area, on the other hand, on the basis of trend experience the female incidence was higher, though not significantly, during the machine period as compared with the non-machine period, while in the case of male mosquitoes for the same period there was a reduction, though that also was not significant. The question now arises that if we were to obtain an expected curve for Garden Reach area by allowing for the changes that have taken place at King George's Docks, on the assumption that the same factors have operated uniformly over both the areas, how far will this expected curve correspond to actual happenings ?

The method we have followed is as follows : Ratios have been calculated for each week with the average experience of King George's Docks as the denominator and the actual experience of 1935-36 in the same area as numerator. Applying these ratios to the average experience at the experimental area we have obtained expected values for each week. We now compare the expected and the actual values of the experimental area for the whole period and obtain the deviations in each case and compare the mean deviation in the pre-machine period with that in the machine period. The calculations are shown for females and males respectively in Tables XII and XIII.

The differences in both cases are insignificant but are in reverse directions; the actuals being higher in the machine period in the case of the females and lower in the case of the males. The obvious conclusion is that the factors responsible for the lowering of the mosquito incidence in the machine period at King George's Docks were not operative at Garden Reach and in any case this analysis does not bring forth evidence of any factors which could have increased the mosquito incidence during the machine period which might counteract the action of the machine.

(C) We can test the efficacy of the machine in another way. If the machine was effective it should have made a significant difference in the shape of the curve of actual catches during the period of its operation as compared with the expected curves calculated on various hypotheses.

To determine a smooth curve from these expected values polynomials of different orders were tried but none of them gave a good fit. The method of moving-averages was therefore employed. The 1935 experience being dissimilar to that of the previous years a correction factor for the pre-machine period was obtained by dividing the total catches for that period in 1935 by the corresponding figure obtained from the smoothed expected values. This factor was applied to the smoothed expected values for the machine period to make the necessary correction on the assumption that the special factors operative in

TABLE XII.

Females—Comparison of the actual weekly catches in the experimental area for 1935-36 *with the expected calculated by correcting the average weekly catches in the experimental area for* 1931–34 *on the basis of the experience of the control area.*

1	2	3	4	5	6	7	8
	CONTROL AREA.			EXPERIMENTAL AREA.			
Number.	Average up to 1934.	Actual 1935.	Ratio (3)÷(2).	Average up to 1934.	Expected 1935.	Actual 1935.	Deviations, expected *minus* actual.
1	8·5	5	0·59	2·75	1·62	1	0·62
2	6·8	1	0·15	1·00	0·15	2	—1·85
3	7·3	1	0·14	3·50	0·49	2	—1·51
4	6·0	2	0·33	3·00	0·99	2	—1·01
5	6·0	..	..	2·50	..	2	—2·00
6	8·8	2	0·25	2·50	0·63	1	—0·37
7	6·0	9	1·50	4·50	6·75	4	2·75
8	4·8	9	1·89	4·50	8·51	4	4·51
9	9·5	9	0·95	2·50	2·38	6	—3·62
10	9·0	12	1·33	4·25	5·65	6	—0·35
11	13·0	14	1·08	5·50	5·94	8	—2·06
12	9·5	15	1·58	4·25	6 72	11	—4·28
13	20·8	13	0·63	6·00	3·78	12	8·22
14	15·0	15	1·00	12·00	12·00	12	..
15	18·3	13	0·71	12·00	8·52	8	0·52
16	18·3	13	0·71	15·00	10·65	11	—0·35
17	22·8	13	0·57	23·25	13·25	14	—0·75
18	21·3	18	0·85	27·75	23·59	18	5·59
19	16·3	20	1·23	23·75	29·21	16	13·21
20	24·5	16	0·65	28·25	18·36	17	1·36
21	31·5	15	0·48	32·50	15·60	12	3·60
22	26·0	18	0·69	38·50	26·57	18	8·57
23	31·3	22	0·70	41·00	28·70	36	—7·30
24	31·8	24	0·75	37·25	27·94	24	3·94
25	37·8	19	0·50	49·00	24·50	26	—1·50
26	48·0	24	0·50	48·75	24·38	34	—9·62
27	50·0	29	0·58	56·50	32·77	25	7·77
28	42·8	34	0·79	51·75	40·88	36	4·88
29	52·0	32	0·62	50·50	31·31	26	5·31
30	43·8	24	0·55	37·00	20·35	25	—4·65

Mean deviation 1—22 weeks = 1·4.
Mean deviation 23—30 weeks = 0·15.
The difference between these is not significant.

1935-36 were evenly effective throughout the period. The mean of the expected values so corrected was compared with that of the actual during the machine period. For calculating the expected values three methods were employed :—

(1) The means of the corresponding weeks for the years 1931–34. The relevant data and the necessary calculations for females and male mosquitoes are given in Tables XIV and XV respectively.

Female mosquitoes.—The mean of the actual value being less than that of the expected it would point towards the efficacy of the machine. However, the difference between the two is not significant.

TABLE XIII.

Males—Comparison of the actual weekly catches in the experimental area for 1935-36 *with the expected calculated by correcting the average weekly catches in the experimental area during* 1931–34 *on the basis of the experience of the control area.*

1	2	3	4	5	6	7	8
	CONTROL AREA.			EXPERIMENTAL AREA.			
Number.	Average up to 1934.	Actual 1935.	Ratio (3) ÷ (2).	Average up to 1934.	Expected 1935.	Actual. 1935.	Deviations, expected *minus* actual.
1	2·0	3	1·50	1·00	1·50	..	1·50
2	2·0	1	0·50	1·50	0·75	..	0·75
3	1·3	..	..	1·75	..	..	..
4	1·0	2	2·00	1·50	3·00	1	2·00
5	1·5	1	0·67	3·00	2·01	1	1·01
6	1·3	1	0·77	3·75	2·89	..	2·89
7	1·3	..	..	2·50	..	1	—1·00
8	2·5	..	..	1·00	..	1	—1·00
9	3·5	1	0·29	1·25	0·36	2	—1·64
10	3·0	3	1·00	3·00	3·00	1	2·00
11	3·8	4	1·05	0·75	0·79	3	—2·21
12	5·0	6	1·20	3·25	3·90	3	0·90
13	7·0	7	1·00	5·00	5·00	7	—2·00
14	6·5	5	0·77	7·75	5·97	5	0·97
15	5·0	8	1·60	5·50	8·80	5	3·80
16	10·5	8	0·76	13·00	9·88	2	7·88
17	12·0	6	0·50	14·00	7·00	5	2·00
18	16·5	7	0·42	12·75	5·36	3	2·36
19	13·8	5	0·36	10·25	3·69	6	2·31
20	20·0	4	0·20	9·25	1·85	2	—0·15
21	14·3	5	0·35	19·50	6·83	8	—1·17
22	8·0	4	0·50	36·75	18·38	11	7·38
23	9·5	4	0·42	31·00	13·02	7	6·02
24	20·5	4	0·20	15·50	3·10	6	—2·90
25	12·5	7	0·56	12·00	6·72	14	—7·28
26	10·0	10	1·00	29·50	29·50	13	16·50
27	10·3	8	0·78	32·75	25·55	21	4·55
28	12·0	5	0·42	22·50	9·45	5	4·45
29	16·0	3	0·19	19·25	3·66	10	—6·34
30	11·5	5	0·43	19·00	8·17	6	2·17

Mean deviation 1—22 weeks = 1·29.
Mean deviation 23—30 weeks = 2·15.
Pooled estimate of the standard deviation = 4·49.

$$t = \frac{2{\cdot}15 - 1{\cdot}29}{4{\cdot}49\sqrt{\frac{1}{22}+\frac{1}{8}}} = \frac{0{\cdot}86}{1{\cdot}85} = 0{\cdot}46 \text{ which is not significant.}$$

Male mosquitoes.—Here the difference is in the reverse direction but again not significant.

(2) The trend values of the corresponding weeks. This method takes into consideration the tendency for the shape of the curve to change from year to year. For detailed information *vide* Tables XVI and XVII.

Female mosquitoes.—The result is unfavourable to the machine though not significantly.

Male mosquitoes.—The result is favourable though insignificantly so.

TABLE XIV.

Females—Experimental area. Comparison of the actual experience in the machine period with that expected on the basis of the mean of 1931–34.

Number.	Mean experience.	Smoothed experience.	(3) made comparable with actual.	Actual.	Deviations, expected *minus* actual.
1	2·8	2·8	..	..	..
2	1·0	2·4	..	..	..
3	3·5	2·5	..	..	..
4	3·0	3·0	..	..	..
5	2·5	2·7	..	..	..
6	2·5	3·2	..	..	..
7	4·5	3·8	..	..	..
8	4·5	3·8	..	..	..
9	2·5	3·8	..	..	..
10	4·3	4·1	..	..	..
11	5·5	4·7	..	..	..
12	4·3	5·3	..	..	..
13	6·0	7·4	..	..	..
14	12·0	10·0	..	..	..
15	12·0	13·0	..	..	..
16	15·0	16·8	..	..	..
17	23·3	22·0	..	..	..
18	27·8	24·9	..	..	..
19	23·8	26·6	..	..	..
20	28·3	28·2	..	..	..
21	32·5	33 1	..	..	..
22	38·5	37·3	..	..	..
23	41·0	38·9	27·8	36	—8·2
24	37·3	42·4	30·3	24	6·3
25	49·0	45·0	32·2	26	6·2
26	48·8	51·4	36·8	34	2·8
27	56·5	52·4	37·5	25	12·5
28	51·8	52·9	37·8	36	1·8
29	50·5	46·4	33·2	26	7·2
30	37·0	37·0	26·5	25	1·5

Total catches for 1935-36 for 1—22 weeks = 187.

Corresponding total from the smoothed experience (column 3) = 261·4.

Correction factor = 187 ÷ 261·4 = 0·71538.

The mean deviation = 3·76.

Standard error of the mean deviation = 2·13.

$t = \frac{3·76}{2·13} = 1·77$. This is not significant.

(3) The expected values in this method are the actual values for 1935-36 for the control area. The advantage in this method is that it takes into account the effect of the abnormal deficiency of rainfall in November 1935. The results for females and males from Tables XVIII and XIX respectively are as follows :—

Female mosquitoes.—The difference is significant and goes against the machine.

Male mosquitoes.—Here also the difference goes significantly against the machine.

Similar test for males is carried out below :—

TABLE XV.

Males—Experimental area. Comparison of the actual experience in the machine period with that expected on the basis of the mean of 1931–34 experience.

Number.	Mean experience.	Smoothed experience.	(3) made comparable with actual.	Actual.	Deviations, (4)—(5).
1	1·0	1 0	..	..	..
2	1·5	1·4	..	..	..
3	1·8	1·6	..	..	..
4	1·5	2·1	..	..	..
5	3·0	2·8	..	..	..
6	3·8	3·1	..	..	..
7	2·5	2·4	..	..	..
8	1·0	1·6	..	..	..
9	1·3	1·8	..	..	..
10	3·0	1·7	..	..	..
11	0·8	2·4	..	..	..
12	3·3	3·0	..	..	..
13	5·0	5·4	..	..	..
14	7·8	6·1	..	..	..
15	5·5	8·8	..	..	..
16	13·0	10·8	..	..	..
17	14·0	13·3	..	..	..
18	12·8	12·4	..	..	..
19	10·3	10 8	..	..	..
20	9·3	13·0	..	..	..
21	19·5	21·9	..	..	..
22	36·8	29·1	..	..	..
23	31·0	27·8	11·9	7	4·9
24	15·5	19·5	8·3	6	2·3
25	12·0	19·0	8·1	14	—5·9
26	29·5	24·8	10·6	13	—2·4
27	32·8	28·3	12·1	21	—8·9
28	22·5	24·9	10·7	5	5·7
29	19·3	20·3	8·7	10	—1·3
30	19·0	19·0	8·1	6	2·1

Total catches in 1935-36 for 1—22 weeks = 67.

Corresponding total from the smoothed experience = 156·5.

Correction factor = 0·42812.

The mean deviation = —0·44.

Standard error of the mean deviation = 1·83.

$\frac{0{\cdot}44}{1{\cdot}83} = 0{\cdot}24$. This is not significant.

TABLE XVI.

Females—Experimental area. Comparison of the actual experience in the machine period with that expected on the basis of the weekly trends of 1931–34 period.

1	2	3	4	5	6
Number.	Trend experience.	Smoothed experience.	Actual.	(3) made comparable.	Deviations, (5)—(4).
23	36·0	23·3	36	20·8	—15·2
24	21·0	30·0	24	26·8	2·8
25	33·0	32·3	26	28·9	2·9
26	43·0	36·5	34	32·6	—1·4
27	33·5	32·2	25	28·8	3·8
28	20·0	19·1	36	17·1	—18·9
29	4·5	13·2	26	11·8	—14·2
30	15·0	15·0	25	13·4	—11·6

Total catches in 1935-36 for 1—22 weeks = 187.
Corresponding total from the smoothed experience = 209·3.
Correction factor = 0·89345.
The mean deviation = —6·48.
Standard error of the mean deviation = 3·33.

$t = \frac{6 \cdot 48}{3 \cdot 33} = 1 \cdot 95$. This is not significant.

TABLE XVII.

Males—Experimental area. Comparison of the actual experience in the machine period with that expected on the basis of the weekly trends of 1931–34 period.

1	2	3	4	5	6
Number.	Trend experience.	Smoothed experience.	Actual.	(3) made comparable.	Deviations, (5)—(4).
23	..	..	7	..	—7·0
24	..	4·5	6	7·8	1·8
25	13·5	12·0	14	20·8	6·8
26	22·5	17·7	13	30·6	17·6
27	17·0	17·3	21	30·0	9·0
28	12·5	12·8	5	22·2	17·2
29	9·0	7·2	10	12·5	2·5
30	..	..	6	..	—6·0

Correction factor = 1·73127.
The mean deviation = 5·24.
Standard error of the mean deviation = 3·29.

$t = \frac{5 \cdot 24}{3 \cdot 29} = 1 \cdot 59$. This is not significant.

TABLE XVIII.

Females—Comparison of the actual experience in the machine period with that expected on the basis of 1935-36 *experience of the control area.*

1	2	3	4	5	6
Number.	1935 experience. Control area.	Smoothed values.	Actual.	(3) made comparable with (4).	Deviations, (5)—(4).
23	22	21·3	36	19·0	—17·0
24	24	21·7	24	19·4	—4·6
25	19	22·3	26	19·9	—6·1
26	24	24·0	34	21·4	—12·6
27	29	29·0	25	25·9	+0·9
28	34	31·7	36	28·3	—7·7
29	32	30·0	26	26·8	+0·8
30	24	24·9	25	21·4	—4·6

With the machine working the experience on the whole has been higher than was expected. Mean deviation is —6·36 and t is 2·93. This is significant.

TABLE XIX.

Males—Comparison of the actual experience in the machine period with that expected on the basis of 1935-36 *experience of the control area.*

1	2	3	4	5	6
Number.	1935 control.	Smoothed values.	Actual.	(3) made comparable with (4).	Deviations, (5)—(4).
23	4	4·0	7	3·3	—3·7
24	4	4·7	6	3·8	—2·2
25	7	7·0	14	5·7	—8·3
26	10	8·3	13	6·8	—6·2
27	8	7·7	21	6·3	—14·7
28	5	5·3	5	4·3	—0·7
29	3	4·3	10	3·5	—6·5
30	5	5·0	6	4·1	—1·9

The experience in this case also has all along been higher than was to be expected without the machine.

Mean deviation is —5·53.

$t = \frac{-5·53}{1·60} = -3·46$ which gives the probability as 0·01 and judged by 5 per cent level is significant.

The significant differences to the disadvantage of the machine are as previously indicated probably due to the dissimilarity of the two areas.

APPENDIX II.

STATISTICAL ANALYSIS OF THE FIGURES RELATING TO EXPERIMENTS WITH ENTORAY MACHINE.

BALLYGUNGE AREA.

The position regarding the breeding grounds and the catching stations has been described in the text. The data available are of a different type. Unlike Garden Reach and King George's Docks we have no record of mosquito catches for the previous years. The comparison of the two places can only be instituted between the period when the machine was working and the period when it had ceased to work. Two tests have been carried out.

(1) A fourfold χ^2 test on the total catches. The results are :—

Female mosquitoes.—A result significantly favourable to the machine.

Male mosquitoes.—A value against the machine though not significantly.

TABLE XX.

Females—Ballygunge area. Comparison of the control and experimental area experiences for the machine and the post-machine periods.

	Experimental area.	Control area.	Totals.
Machine period ..	25·4	77·2	102·6
Non-machine period ..	20·9	26·5	47·4
TOTALS ..	46·3	103·7	150 0

$\chi^2 = 5{\cdot}67$. This is significant.

TABLE XXI.

Males—Ballygunge area. Comparison of the control and experimental area experiences for the machine and the post-machine periods.

	Experimental area.	Control area.	Totals.
Machine period ..	19·1	12·2	31·3
Non-machine period ..	16·3	21·8	38·1
TOTALS ..	35·4	34·0	69·4

$\chi^2 = 2{\cdot}29$ which is not significant.

(2) The mean deviations (control *minus* experimental) of the daily catches for the machine and non-machine periods are compared for females and males in Tables XXII and XXIII respectively.

The results are :—

Females.—The incidence is significantly less in the machine period.

Males.—The incidence is significantly higher in the machine period.

TABLE XXII.

Females—Ballygunge area. Comparison of the control and experimental area experiences during the machine and the non-machine periods.

MACHINE PERIOD (FEBRUARY).				NON-MACHINE PERIOD (MARCH).			
Date.	Control area.	Experimental area.	Deviations, control *minus* experimental.	Date.	Control area.	Experimental area.	Deviations, control *minus* experimental.
6	22	31	—9	1	71	14	57
7	34	40	—6	2	46	15	31
8	69	44	25	3	32	22	10
9	65	28	37	4	80	48	32
10	104	28	76	5	79	65	14
11	111	41	70	6	97	50	47
12	124	44	80	7	68	48	20
13	112	59	53	8	85	57	28
14	73	32	41	9	92	49	43
15	34	21	13	10	45	23	22
16	103	22	81	11	2	25	—23
17	96	13	83	12	15	14	1
18	99	21	78	13	9	22	—13
19	97	33	64	14	19	14	5
20	43	12	31	15	12	12	..
21	49	14	35	16	3	7	—4
22	103	13	90	17	9	18	—9
23	92	24	68	18	3	7	—4
24	83	22	61	19	5	7	—2
25	56	11	45	20	1	17	—16
26	61	8	53	21	2	10	—8
27	102	18	84	22	1	12	—11
28	51	9	42	23	1	5	—4
29	70	21	49	24	0	11	—11
..	..	..	..	25	5	3	2
..	..	..	..	26	12	18	—6
..	..	..	..	27	6	14	—8
..	..	..	..	28	2	5	—3
..	..	..	..	29	6	12	—6
..	..	..	..	30	9	9	..
..	..	..	..	31	4	15	—11

Mean deviation machine period $= \frac{1244}{24} = 51{\cdot}83.$

Mean deviation non-machine period $= \frac{173}{31} = 5{\cdot}58.$

Pooled estimate of the variance $= 559{\cdot}64.$

$$t = \frac{51{\cdot}83 - 5{\cdot}58}{23{\cdot}06\sqrt{\frac{1}{31} + \frac{1}{24}}} = \frac{46{\cdot}25}{6{\cdot}44} = 7{\cdot}18.$$ This is significant.

TABLE XXIII.

Males—Ballygunge area. Comparison of the control and experimental area experiences during the machine and the non-machine periods.

MACHINE PERIOD (FEBRUARY).				NON-MACHINE PERIOD (MARCH).			
Date.	Control area.	Experimental area.	Deviations, control *minus* experimental.	Date	Control area	Experimental area.	Deviations, control *minus* experimental
6	25	30	—5	1	26	11	15
7	26	46	—20	2	47	15	32
8	10	38	—28	3	21	8	13
9	20	9	11	4	79	18	61
10	2	24	—22	5	76	43	33
11	6	17	—11	6	97	62	35
12	4	9	—5	7	84	44	40
13	7	9	—2	8	78	48	30
14	8	10	—2	9	72	45	27
15	9	11	—2	10	32	12	20
16	23	16	7	11	2	13	—11
17	3	19	—16	12	12	10	2
18	1	36	—35	13	1	14	—13
19	7	44	—37	14	1	12	—11
20	5	14	—9	15	5	17	—12
21	8	16	—8	16	3	3	..
22	7	16	—9	17	7	14	—7
23	10	16	—6	18	1	8	—7
24	36	13	23	19	1	5	—4
25	7	4	3	20	3	11	—8
26	10	13	—3	21	4	20	—16
27	17	11	6	22	4	13	—9
28	10	11	—1	23	3	5	—2
29	33	25	8	24	1	7	—6
..	..	..	..	25	2	13	—11
..	..	..	..	26	2	11	—9
..	..	..	..	27	4	10	—6
..	.	..	..	28	1	0	1
..	..	..	..	29	0	2	—2
..	..	..	..	30	3	4	—1
..	..	..	..	31	3	8	—5

Mean deviation machine period $= \frac{-163}{24} = -6{\cdot}79.$

Mean deviation non-machine period $= \frac{169}{31} = 5{\cdot}45.$

Pooled estimate of the variance $= 305{\cdot}87.$

$t = \dfrac{5{\cdot}45 + 6{\cdot}79}{17{\cdot}49\sqrt{\frac{1}{31} + \frac{1}{24}}} = 2{\cdot}57.$ This is significant for 5 per cent level.

The results of all the tests carried out can be summarised as follows :—

Actual catches under machine influence compared with	Significance brought out or not 5 per cent level is taken. (+) result favourable to machine. (—) result against machine.	
	Females.	Males.
GARDEN REACH AREA.		
I. The trend values for 1935 of the experimental area 1931–34 experience.	(—) Not significant.	(+) Not significant.
II. The trend values for 1935 of the experimental area. 1931 experience excluded.	..	(+) Not significant.
III. The expected after allowing for sudden changes in the machine period.	(—) Not significant.	(+) Not significant.
IV. Mean values of experimental area Only period 23–30 weeks is considered.	(+) Not significant.	(—) Not significant.
V. Trend values of experimental area. Only period 23–30 weeks is considered.	(—) Not significant.	(+) Not significant.
VI. Control area 1935 curve. Period 23–30 weeks only.	(—) Significant	(—) Significant.
BALLYGUNGE AREA.		
I. χ^2 test	(+) Significant	(—) Not significant.
II. Mean deviation test	(+) Significant	(—) Significant.

As is clear from these results the use of the machine does not seem to have produced any reduction in the number of mosquitoes.

CONCLUSIONS.

1. The 'Entoray' machine does undoubtedly catch mosquitoes, if not of all, of many species.
2. Its radius of attraction is very much less than the distance claimed for it, certainly less than 70 yards.
3. It is not capable of making any statistically significant difference in mosquito incidence even within a few feet of its point of operation.
4. It does undoubtedly furnish a new method of investigation into the composition of the mosquito fauna of an area, and can be used to acquire valuable information of mosquito movements during the hours of darkness.

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A GENERAL REVIEW OF THE PROBABLE LARVIVOROUS FISHES OF INDIA.

BY

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INTRODUCTION.

THE Malaria Survey of India published in 1927 a bulletin entitled 'Table for the identification of some Indian Freshwater Fish' (Malaria Bureau, 1927)* for the use of the classes in Malaria training, based on 'Fishes' in the *Fauna of British India* Series (Day, 1889). Monumental as Day's work was for the times when it was issued, it is, in view of the great deal of recent work on the classification of fishes and the advances in our knowledge of the distribution, habits, etc., of the Indian fishes, out of date. One of the authors, therefore, suggested to Lieut.-Col. J. A. Sinton, V.C., I.M.S., Director, Malaria Survey of India, in 1934, that the second edition of the bulletin should not only contain a more detailed and properly illustrated account of the Indian fishes which have proved useful or are likely to prove of value as larvivorous forms, but that the nomenclature, etc., of the various species dealt with should be brought up to date. We were recently requested by the authorities of the Malaria Survey of India to undertake the work, and in the present paper, in addition to a brief review of the literature of the Indian larvivorous species, we discuss the value, so far as is known, of the various Indian and two exotic species, and generally deal with the question of the biological control of mosquitoes by fishes. A detailed account of the various species with keys for their identification will later be published in a revised edition of the bulletin, which is being prepared by Mr. D. D. Mukerji of the Zoological Survey of India.

We would, however, like to make it clear that in advocating a more extensive use in India of the principle of biological control—in this instance

* In the review of the literature the correct scientific names of fishes, if different from those used by the various authors, are also given within brackets.

by larvivorous fishes—for anti-malarial measures we do not mean to decry entirely the use of chemical larvicides. Such chemical larvicides are, for example, specially valuable in waters of a temporary nature, where biological control with fish or other animals would be impossible. All the same their use in tanks, *bheels* and such other large areas of water which support valuable fisheries and often are the sources of water-supply of the local population cannot be recommended.

In the preparation of this paper we have received valuable suggestions from Lieut.-Col. G. Covell, I.M.S., and Dr. I. M. Puri of the Malaria Survey of India and the cost of preparation of the illustrations has been met by the same department. Mr. D. D. Mukerji has helped us materially in getting together the scattered literature on the subject; and has also supervised the execution of the drawings of the fish by Babu B. N. Bagchi.

REVIEW OF LITERATURE.

It has long been known that several species of fish feed on the aquatic larvæ of various classes of insects, including mosquitoes, and in different parts of the world they have been used for many years for clearing small tanks, pools and other permanent or semi-permanent areas of waters of such larvæ. According to the very useful summary in the pamphlet on the use of fish for mosquito control issued by the International Health Board of the Rockefeller Foundation (1924), 'the use of fish (generally perch) in open shallow wells to keep down mosquitoes and "purify the water" is said to have been a household custom for generations in the United States. In Georgia in 1854, a certain Dr. Fort freed a tank of all its larvæ by placing in it a dozen or more small fish. It was noticed by a Mr. Russell in Bridgeport, in 1891, that all larvæ had disappeared from a pool left by a receding tide which had brought in a number of small fish. In a neighbouring pool of the same sort, which contained no fish, the larvæ were very numerous'.

Active interest in the subject, however, began from about 1900 when investigations—unfortunately disconnected and incomplete in most cases—were initiated in different parts of the world to determine the utility of various species of fish for mosquito control. The results of these investigations were not, in general, of any permanent value, as laboratory experiments were seldom backed by field work, while the field work was not carried out with sufficient care or on any extensive scale for the results to be conclusive. Very careful and elaborate investigations were, however, made for the United States Fish Commission, particularly by Seal and Moore, in different parts of the United States, and as a result fish are now commonly used by the United States Public Health Service in anti-malarial campaigns. In other parts of the world similar work has been attempted, and a detailed summary of it is to be found in the pamphlet of the International Health Board referred to above. The question of biological control of mosquitoes by fish and other natural agencies is also discussed in some detail in Fermi's Manual (1935) on anti-malarial work. In this publication the author particularly discusses the use of the American top-minnow, *Gambusia affinis,* and lists various European and exotic species which have proved of value for larvicidal work. We give below a summary of the more important work in reference to India.

About a quarter of a century ago suggestions were made to import the popularly known 'Barbados Millions' (*Lebistes reticulatus,* generally referred

in literature as *Girardinus poeciloides*) for reducing the mosquito pest in India. This suggestion was presumably based on the assumption that there are no indigenous Indian fish which feed on mosquito larvæ and can play the same rôle as the 'Millions' do in Barbados. 'Millions' were accordingly introduced on one or two occasions, but it was found that the species could not be acclimatised in Northern India. This, however, stimulated workers to investigate the indigenous species with a view to determining their propensities as larvivorous forms. Experiments, generally under laboratory conditions, were carried out mainly by medical and health authorities in various parts of the country and the results, though conflicting at times and contradictory in places, were fruitful in so far as several mosquito-destroying species of indigenous fish were discovered. These laboratory investigations had, however, not been tried in the field on a sufficiently large scale when the work was interrupted due to the outbreak of the World War in 1914. Since the War malarial surveys and extensive anti-malarial work have been in progress all over India by the Malaria Survey of India, the Public Health Departments of the various local Governments, Corporations, Municipalities, local bodies, etc., but unfortunately larvicidal fish have not been used to the same extent in mosquito-control measures as one would have hoped from the results achieved before the War.

Ross investigated the use of fish in the early nineties of the last century and found minnows (species not indicated) devouring in a few seconds a dozen or more mosquito larvæ. He also noticed that fish and larvæ were found living together in ditches and rice-fields and that large fish seldom, if ever, fed on mosquito larvæ.

Aitken (1901) appears to be the pioneer after Ross to state in unequivocal terms that 'of all larvicides, the most effectual, in the case of *Anopheles,* is little fishes. I have never found larvæ and fishes in the same pool'. He advocated two species as particularly useful, one the indigenous 'Piku' fish (*Panchax lineatus*) and the other the exotic Gold-fish (*Carassius auratus*). He also casually referred to other insect enemies of mosquito larvæ, such as the dragonfly larvæ, but was of opinion that 'one fish will do more than a hundred of these'.

Alcock (1902) observed at Aucutta Island in the Laccadive Sea that the wells and tanks 'positively swarmed with a little species of carp (*Barbus*), and with two species of sea-fishes acclimatised to fresh water'. As a result no mosquitoes were found on this island, while they were in abundance in the adjacent island of Minnikoy where in the wells and tanks these fishes were almost absent. In the first edition of his well-known work 'Entomology for Medical Officers' Alcock (1911) referred to the well-established laws of nature, and in considering the 'Natural Enemies' of mosquito larvæ, suggested the use of small fishes of the family Cyprinodontidæ as larvivorous forms. In the second edition of this work (Alcock, 1920) fishes were placed first among the natural enemies of mosquito larvæ with the remark 'particularly those that frequent the surface, and especially *Cyprinodontidae,* which are found all round the globe in low latitudes and can live in water of any quality and temperature'. He, however, concluded that 'although natural enemies have their application in these and similar circumstances, they are a minor consideration of rural sanitary policy'.

Osborn (1907) advocated the use of 'Chilwa' (*Chela argentea*) as a very valuable larvicidal fish in view of the fact that the species is a surface-feeder and is easily procurable in most parts of India. He conducted some experiments in a cistern about 8 to 9 feet long by 5 feet broad and 5 feet deep and found that 50 or 60 'Chilwa' were able to clear every mosquito larva in the cistern within a week or so.

Brahmachari (1909) in connection with a campaign against malarial fever in Cossipore-Chitpore Municipality in Bengal found that in tanks clear of weeds, mosquito larvæ were restricted to the edges of the freshwater tanks, and observed that 'Techoko' (*Panchax panchax*) were found preying on them in very large numbers. He, therefore, concluded that 'the importance of this agency when not interfered with by weeds in keeping down the malarial intermediaries cannot be exaggerated'.

Chaudhuri (1909) investigated the mosquito-larva-eating propensity of fishes of the genus *Haplochilus* (= *Panchax* and *Aplocheilus*) and found that these 'tiny surface-swimming fishes possess ravenous appetite for living and moving larvæ in water, and that they eat the wriggling larvæ of mosquitoes with great avidity'. He further found that even under natural conditions these fish are equally efficient for destroying mosquito larvæ. Experiments were, according to the author, being conducted to determine the numbers of fish that would be required for keeping an area of known dimensions, of a stagnant or confined nature, free of mosquito larvæ.

Chaytor-White (1910), after discussing the utility of larvivorous species of fish in different parts of the world, suggested the propagation of various indigenous species, particularly of the top-feeders such as the 'mullets', with a number of which he had experimented successfully in various districts of the United Provinces.

The Imperial Malaria Conference held in Simla in October 1909 passed the following resolution :—'It should be ascertained by enquiry and experiment whether the breeding of anopheline mosquitoes is greatly checked by the presence of fish in tanks and other collections of water; and if this is found to be the case, endeavours should be made to introduce suitable fish where their presence is likely to prove beneficial, and to afford protection to them where they exist'. Unfortunately the very important question dealt with in this resolution does not seem to have been investigated or acted upon to any extent.

Bentley (1910) in connection with malaria work in Bombay repeated experiments with Aitken's 'Piku' fish and found it very useful as a larvicidal form, provided it was 'present in sufficient numbers' and was not 'hampered by floating weed or rubbish'. He found this species of fish particularly effective for clearing wells of mosquito larvæ. The other species, 'Kazari' (*Anabas testudineus*) which is also a surface-feeder, was found to be equally useful for destroying *Anopheles* larvæ and pupæ; he recommended this species for stocking wells, tanks or ornamental fountains. *Polyacanthus cupanus* (*Macropodus cupanus*) was found to be larvivorous, but not so efficient as *A. testudineus*, while 'Chilwa' (*Chela argentea*) was found to be not so efficient as the other three species enumerated above.

Bannerman (1910) confirmed Bentley's observations regarding the efficiency of 'Piku' as a larvicidal form. Fishes of this species kept by him in a fernery at Parel altogether cleared that area of mosquito larvæ.

Lloyd (1911) in a short note referred to the supposed value of the 'Millions' for reducing malaria in Barbados and in this connection remarked that a natural balance exists between the numbers of any species and the amount of food that is available for their nutrition. It, therefore, follows that a given volume of natural water cannot support more than a certain weight and number of fish, and if the fresh waters of Barbados swarm with a particular kind of fish, this species must have some special source of nutriment. He referred to the investigations with *Haplochilus* (*Panchax panchax*) in Bengal as a larvicidal form, and from his own observations in the Zoological Gardens at Alipore, Calcutta, concluded that the species was not so efficient for larvicidal campaigns, as had been affirmed by other workers.

Chaudhuri (1911) dealt in general with the various steps suggested for the control of the mosquito larvæ in permanent breeding grounds and strongly condemned the use of larvicides of a chemical nature for mosquito control in waters containing fish and other animals. He recommended the improvement of the drainage in such localities, as he believed that by drainage they are made particularly suitable for fish. He gave an account of his experimental work with the indigenous fishes for determining their larvivorous propensities and outlined the necessary characteristics of fishes to be selected for such work; these, with slight modifications, have been adopted by the Malaria Survey of India as a standard (*vide infra*, p. 638). The species, which he found particularly useful for larvicidal work, were *Haplochilus panchax* (*Panchax panchax*), *Badis badis*, *Ambassis nama*, *Trichogaster fasciatus* (*Colisa fasciata*), *Anabas scandens* (*A. testudineus*), *Barbus phutunio*, *Nuria danrica* (*Esomus danricus*), *Notopterus kapirat* (*N. notopterus*) and *Rasbora daniconius*. He also considered *Perilampus atpar* (*Laubuca atpar*) and *P. laubuca* (*Laubuca laubuca*) as being of some practical utility. Chaudhuri's paper contains a very useful review of the whole subject, while the information regarding the local names and habits of the different species makes it specially valuable for reference.

Fry (1912) listed the common larvicidal fishes of Bengal fresh waters as *Haplochilus panchax* (*Panchax panchax*), *H. melastigma* (*Aplocheilus melastigma*), *Ambassis nama*, *A. ranga*, *Barbus ticto* and several species of the genus *Trichogaster* (= *Colisa* and *Trichogaster*). As a result of his work he observed that permanent waters with any of these larvicidal forms, 'if free of weed and with clean cut sides without grass or bush and with no shelving mud flats', were found to be free of the larvæ. *Culex* and *Anopheles* larvæ are found in abundance if excessive and thickly matted weed is present, while only anopheline larvæ are found if the weed is not very excessive and the edges are shelved. In his opinion, indigenous fish were sufficiently numerous to deal with mosquito larvæ and importation of foreign species was unnecessary. The tanks and other permanent waters to be dealt with must be freed of weed and have their edges clean and steep cut. Borrow-pits, etc., should be connected with one another and made sufficiently deep, so that they may not dry up altogether at any time of the year, as this would result in the death of the fish population. He also added that chemical larvicides should be used with discretion so as not to destroy fish and other animal life.

Sewell and Chaudhuri (1912) published a pamphlet entitled 'Indian Fish of Proved Utility as Mosquito Destroyers' from the Zoological and Anthropological Section of the Indian Museum. Various Indian species of fish, which had

been found useful as mosquito destroyers, are described in detail, and very good illustrations of the different species are published. The popular names of the species in different parts of India are noted, and their distribution is discussed. At the end is appended a list of such species as feed on mosquito larvæ in the early stages only. In the additional notes Sewell gave a short account of various larvivorous species in their natural surroundings, based on observations in various *nullahs* in the Sialkot District of the Punjab and also as a result of investigations in various freshwater tanks and *bheels* in some of the districts in Bengal and in the brackish water tanks at Port Canning near Calcutta. According to his observations, larvæ were absent in the tanks where any of the species of larvivorous fish enumerated in the pamphlet were present in sufficient numbers. Such tanks as were free of mosquito larvæ were found 'side by side with others in which larvæ were breeding freely, in many cases being separated by a distance of a few yards only; and, moreover, where cattle, etc., had made small holes in their margin in which water had collected and to which fish had not got access, larvæ of all kinds were common'. In regard to water weeds, he was of opinion that 'in the main their presence does not in any way prevent the complete clearance of larvæ by these small fish, but there are one or two kinds that seem worthy of note'. Amongst such forms are the water-lilies and other aquatic plants that possess fairly large flat leaves; these apparently protect the larvæ from the attacks of small fish.

O'Donnell published a report on the importation of 'Millions' into India, and the results of experiments with these fishes as destroyers of mosquito larvæ in 1912; this was reprinted in the *Records of the Malaria Survey of India*, Vol. I (1930). The importation of 150 'Millions' from the Colonial Office, London, to India in 1909 by Major Selby is described, but none of them survived as they could not stand a temperature of 85° or so. Reference is also made to the experiments carried out in the Imperial Research Institute, Pusa, by Mr. F. M. Howlett. Howlett as a result of his experiments concluded that 'Millions' and the Climbing-Perch (*Anabas testudineus*) are more hardy and better destroyers of mosquito larvæ than the 'Chilwa'. He, however, remarked that as temporary accumulations cannot of course be easily populated with fish, 'Permanent enclosed waters are, it would seem, the only place where fish can be tried with a probability'. According to the summary in the report, as a result of experiments with the local indigenous fishes carried out at various places in the United Provinces, fishes of the genera *Ambassis*, *Barbus*, *Nuria* (*Esomus*) and *Trichogaster* (*Colisa* and *Trichogaster*) were found to be good destroyers of mosquito larvæ.

Graham (1913) published notes on the larvæ-destroying fish in the United Provinces, but we are unable to discuss this work as it is not available in any of the Calcutta libraries.

In connection with a malaria survey of Delhi, Hodgson (1914) tested numerous species of fish from tanks and ponds round Delhi, and found that *Trichogaster fasciatus* (*Colisa fasciata*), *Barbus phutunio*, *Nuria danrica* (*Esomus danricus*), and *Ophicephalus punctatus* were useful as larvivorous forms. Of these, according to the author, '*Trichogaster* seemed much the most effective, besides being the hardiest. A good fish, when accustomed to captivity, could consume quite 200 larvæ a day'.

Macdonald (1914) pointed out the value of larvicidal fish as an adjunct to other anti-malarial measures and noted that in Madras city stocking of

tanks and wells with such fish was being extensively carried out. Of the various fishes, species of the genus *Haplochilus* (*Panchax* and *Aplocheilus*) were found to be the most voracious and hence most useful. He concluded that stocking of tanks by ' larvicidal fish cannot replace other anti-malarial measures ....it is a most valuable aid in all cases where permanent works are barred for financial reasons '. Trimming of vegetation, removal of weeds and filling up of shallows and hollows in areas to be stocked with larvicidal fish is, according to this author, necessary before the fish are introduced.

Wilson's earlier paper (1913) has unfortunately not been available to us but his later detailed work (Wilson, 1914) is a mine of information on the treatment by larvicidal fish of swamps, stream-beds, ponds, wells, pools, and other mosquito-infested areas. In this pamphlet detailed suggestions are given for the treatment of such areas before the fish are introduced. The various natural enemies of mosquito larvæ are discussed and he considers species of the genera *Chela, Rasbora, Barilius, Haplochilus* (*Panchax* and *Aplocheilus*) and *Barbus* as specially suitable for stocking freshwater tanks, big ponds and swamps. For paddy-fields, wells and small ponds, etc., he recommends fishes of the genera *Chela, Haplochilus* (*Panchax* and *Aplocheilus*) and *Polyacanthus* (*Macropodus*), while for salt and brackish water ponds he considers the genera *Therapon* and *Polyacanthus* as most suitable. This paper, which is fairly well illustrated, is a very valuable contribution to the subject, and should be consulted in original for detailed information.

Murphy (1914) during his extensive tours in Nawabashah, Hyderabad and parts of Karachi District in Sind investigated various indigenous fishes to test their larvæ-eating propensities. He found that the smaller fish of the species, *Cirrhina mrigala, Ambassis ranga, Perilampus atpar* (*Laubuca atpar*), *Nuria danrica* (*Esomus danricus*), *Barbus terio* and *Gobius giuris* (*Glossogobius giuris*), were all useful as larvicidal forms. Some other species, which could not be identified, were also found to have larvivorous propensities. According to him, no mosquito larvæ were found in any pool in which any of the five species of the fish listed above were present, and a decided preference was shown by the fishes for larvæ rather than pupæ.

Prashad (1919) in considering the importance of insects to fisheries discussed in a general way the question of the utility of fish as destroyers of mosquito larvæ. He remarked that unfortunately the habits of various indigenous fishes have not been studied in detail and certain species have been used rather indiscriminately as larvivorous forms. He suggested that the problem should be tackled scientifically, and not only the habits of the more hardy of small surface-feeding fishes should be studied, but a detailed knowledge of the quality and quantity of the food of these fishes under natural conditions, together with their capability for acclimatisation is necessary before they can be employed for destroying mosquito larvæ in different parts of India.

In discussing the fish and mosquito larvæ in Bengal, Southwell (1920) dealt with various permanent freshwater areas such as *bheels*, borrow-pits, tanks, etc. He lists the following species as being of special importance as larvivorous forms: *Haplochilus panchax* (*Panchax panchax*), *H. melastigma* (*Aplocheilus melastigma*) and *H. lineolatus* (*Panchax lineatus*). *Ambassis nama, A. ranga, Trichogaster fasciatus* (*Colisa fasciata*), *Badis badis, Barbus phutunio, Anabas scandens* (*Anabas testudineus*), *Wallago attu, Perilampus* sp. (*Laubuca* sp.),

Danio rerio (*Brachydanio rerio*), *Barilius* sp. and *Rasbora daniconius* are considered to be less useful than the above-listed species. Considering the problem on broader lines he came to the conclusion that the actual reduction of mosquitoes through the agency of fish is not at present a practical scheme. He, however, was of opinion that the cultivation of carp along with mosquito-larvæ-eating fish may prove useful, but care must be taken to remove all predatory fish, as otherwise both the larvicidal fish and the carp fry are likely to be destroyed by the predatory forms.

Hora (1927) discussed the general question of the use of fishes for the control of mosquitoes and cited various examples of the utility of the different larvicidal forms for reducing mosquitoes in a number of areas. He deprecated the policy of importation of exotic larvicidal fishes and even of species from one province to another. He suggested that local species should be investigated for their larvicidal propensities, and selection made from them rather than importing larvivorous fishes from outside, as these are likely to change their habits in the new environments. He favoured with Prof. Tillyard 'the method of biological control—an introduction of hostile insects to fight the pests rather than the chemical method of spraying or fumigation', which is merely 'temporary and also costly'.

In the very useful and handy bulletin on 'Anti-mosquito Measures' Covell (1927) included larvicidal fish amongst the various agencies used for the destruction of mosquito larvæ, and remarked 'these have been used with success in America, but their efficiency is limited'. He recommended the following four genera, *Haplochilus* (*Panchax* and *Aplocheilus*), *Barilius, Chela* and *Barbus,* as the most useful larvivorous Indian forms, and enumerated the following requirements (based on Chaudhuri's paper) as necessary for a really useful larvicidal form :—

'(1) They must be small, so that they can get about in shallow water among weeds, etc.
(2) They must be hardy, and flourish in both deep and shallow waters.
(3) They must be able to breed freely in confined water areas.
(4) They must be able to stand transport and handling.
(5) They must be difficult to catch, and able to escape their natural enemies, including man.
(6) They must be absolutely worthless and insignificant as food.
(7) They must be top-feeders and carnivorous'.

Chatterjee (1934, 1934*a*, 1935) in a series of publications has discussed the malaria problem in Bengal and its biological control by fishes in the rural areas. He deals with the more common larvivorous species of fish of the province and also discusses the factors which are necessary for biological control with fishes to be successful in anti-malarial measures. His work is based on extensive observations in the field, and is particularly useful in connection with the employment of fish as larvicidal agents on an extensive scale.

Reference may also be made to a circular entitled 'The Value of Fish as Natural Enemies of Mosquitoes in Combating Malaria' by Sundara Raj of the Madras Fisheries, in which the author discusses the value of fish as larvicides, the choice of fish for such work and the most useful larvicidal species of South India. He gives details for the preparation of tanks and ponds which it is proposed to stock with larvicidal fishes, and also adduces reasons for

obtaining the larvicidal fish for stocking such areas from fish farms and not from local waters. In it are also included instructions for the methods of transport of the fish, as also the disposal of the fish consignments after they are received.

An exhaustive list of other published, unpublished or local reports on the use of fish as larvicides is to be found in the detailed 'Bibliography of Malaria in India' by Sinton (1929).

PROBABLE LARVIVOROUS FISHES OF INDIA.

We group the larvivorous fishes of India into three main divisions :—

(1) Predaceous species.
(2) Larger species of commercial importance.
(3) Small carnivorous species.

(1) *Predaceous species.*—The Indian fishes of this division belong to the order Siluroidea (Cat-fishes), and the families Ophicephalidæ (Snake-headed fishes) and Gobiidæ (Gobies). Their young undoubtedly feed on mosquito larvæ, at least in the earlier stages, and may thus be beneficial, but in the adult stage besides being useless as larvivorous forms, they feed on smaller species, several of which are very useful larvicidal agents. When any tank or such area is to be stocked with larvivorous species, efforts should be made to clear it of all predaceous forms as far as possible. Two species of the order Siluroidea, *Mystus tengara* (Plate IX, fig. 2) and *Wallago attu* (Plate IX, fig. 3), and one of the Ophicephalidæ, *Ophicephalus gachua* (Plate IX, fig. 5), are figured. Reference may also be made to Murphy's (*loc. cit.*) observations on *Glossogobius giuris*, who considered it useful as a larvicidal form, but this observation needs further confirmation, and in any case this species is probably not larvivorous throughout its life.

(2) *Larger species of commercial importance.*—The fishes of this section constitute the large carps of the family Cyprinidæ such as *Labeo rohita, Catla catla, Cirrhina mrigala*, etc., and are of considerable economic importance as food fishes. The young of these fishes, which are surface-feeders, feed on larvæ of mosquitoes and other insects, while the adults are mainly herbivorous and do not, as a rule, feed on insect larvæ. In nature, however, their utility as larvicidal forms must be strictly limited, as they do not breed in confined waters. Most of the species are among the principal food fishes of India, and in Bengal every year during the rains large numbers of tanks and such areas are stocked with millions of the fry of these fishes. This fry, as suggested by Southwell (*loc. cit.*), may help in keeping down mosquitoes up to the fingerling stage.

(3) *Small carnivorous species.*—This division consists of small carnivorous species of the families Cyprinodontidæ, Anabantidæ, Osphronemidæ, Polyacanthidæ, Pristolepidæ, Ambassidæ, Cyprinidæ and two exotic species of the family Pœcilidæ, which from the available information appear to feed on mosquito larvæ throughout their life. They are mostly small, hardy species with a wide range of distribution. Of the Cyprinodontidæ or the toothed-carps, the most suitable species for mosquito control, according to Chaudhuri, is a species of top-minnow—*Panchax panchax* (Plate X, fig. 8)—which is easily distinguished by a shining, silvery spot in the middle of its head. Chaudhuri (1911) remarks about *P. panchax* that it 'is decidedly the best of the lot and has been

conclusively found by far the most useful in keeping down mosquito larvæ, in as much as it does not eat anything dead or inanimate even to the extent of death by starvation. As the habit of the fish is to remain afloat on the surface, it is particularly destructive to anopheline larvæ which, in order to breathe, must lie flat on the surface of the water'. This species is found from Orissa, through the lower portions of Bengal, Burma, Siam to the Malay Archipelago, and attains about 3½ inches in length. In peninsular India and Ceylon this species is replaced by *P. lineatus* (Plate X, fig. 7) which attains about 4 inches in length and has been reported by most authorities, who have experimented with it, as being as efficient a larvivorous form as *P. panchax.* Two other Cyprinodont fishes, which have been considered useful as larvicidal forms, are: (*i*) *Aplocheilus melastigma* (Plate X, fig. 6), which rarely exceeds 1½ inches in length and is distributed throughout South India, Orissa, Lower Bengal and Burma; and (*ii*) *Lebias dispar* (Plate X, figs. 9 and 10), which is found in India only in Cutch and parts of Sind, and has been found to keep drains, etc., free of mosquitoes. It is fairly common in Abyssinia, Palestine and along the shores of the Red Sea and can probably be introduced and acclimatised in most parts of northern India. About its efficacy, we give below an extract from a letter received by one of us from Dr. E. P. Hicks, Malaria Research Officer, Karachi:

> 'They live in a *kachcha* drain, which carried off the water from a spring lying near the western boundary of Karachi Air Port. I am told that they have been there for at least four years, that they have increased in number, and that the stock has not been replenished. The water is brackish, containing chlorine equivalent to 273·9 parts of sodium chloride per 100,000 parts of water.
>
> No mosquito larvæ have been found by us in the drain, and in the laboratory the fish have been seen to eat larvæ'.

A group of small Labyrinthine fishes of India of the families Anabantidæ, Osphronemidæ and Polyacanthidæ is also believed to be very useful as destroyers of mosquito larvæ. These fishes are characterised by the possession of labyrinthine organs above the gills which enable them to breathe atmospheric air direct. On account of this air-breathing capacity they can live in foul water and be transported easily from place to place. Of this type we illustrate here 4 species belonging to 4 different genera. The fishes of the genus *Colisa,* of which we figure *C. fasciata* (Plate XI, fig. 11), are found throughout India, Burma and Ceylon. The so-called Climbing-Perch, *Anabas testudineus* (Plate XI, fig. 12), is much more widely distributed, but as this fish and most of the species of the genus *Colisa* are prized as food fishes, it is very doubtful whether they will be left undisturbed by man to play their rôle as larvicidal forms in anti-mosquito campaigns. The representatives of the other two genera, *Ctenops* and *Macropodus,* are localised in distribution. *Ctenops nobilis* (Plate XI, fig. 13) is found in the rivers of north-east Bengal and Assam, while *Macropodus cupanus* (Plate XI, fig. 14) is found in ditches, paddy-fields and shallow waters of the Malabar and the Coromondal coasts and in the hills of South India.

Two other allied genera have to be considered in this section. These are *Badis* (Pristolepidæ) and *Ambassis* (Ambassidæ). Of the former there are two small species, *Badis badis* (Plate XII, fig. 15) which is distributed in the fresh

waters of India and Burma and attains a size of 4 inches, and *B. dario* which is a somewhat smaller species and is confined to northern Bengal, Bihar, Burma and the Western Ghats. The genus *Ambassis* comprises several marine and freshwater species. Five or six are confined to fresh waters, and two, *A. ranga* (Plate XII, fig. 16) and *A. nama,* are widely distributed throughout India. They are rather delicate fishes and can, therefore, be used with advantage only in the neighbourhood of their normal habitats.

Among the Cyprinidæ or the toothless carps there are members of three sub-families which have to be considered. The Abramadinæ, of which *Chela* and *Laubuca* form the principal Indian freshwater genera, are characterised by a sharp and cutting abdominal edge. From the structure of their mouth and coloration they appear to be surface-feeding forms, but doubts have been expressed about the utility of *Chela* by a number of workers, and further experimental work is badly needed to adjudge the value of species of this genus as larvicidal forms. It may also be noted that as *Chela* is eaten in large quantities by the poorer classes, its introduction as a larvicide is not likely to prove very satisfactory. The genus is represented throughout India by about a dozen species, all of which are popularly known as the 'Chilwa'. We illustrate one of the commonest species of northern India—*C. bacaila* (Plate XII, fig. 17). The genus *Laubuca* is represented in Indian waters by three small species, one of which is restricted to Ceylon, while the other two are fairly widely distributed in India. The species figured here—*L. laubuca* (Plate XII, fig. 18)—is found in Ganjam, Orissa, Bengal, Assam and Burma and attains about 3½ inches in length. Of the second sub-family Rasborinæ, the genera *Esomus, Danio, Brachydanio* and *Rasbora* are of importance for mosquito control. A number of species of the genus *Esomus* are found living in comparatively shallower waters all over India. We illustrate one of the common species *E. danricus* (Plate XIII, fig. 19). Most of the species of *Danio* and *Brachydanio* are found in the clear and cool waters of the hills, but there is one small species, *B. rerio* (Plate XIII, fig. 20), which occurs in shallow waters all over Bengal. The species of the genus *Danio,* such as *D. aequipinnatus* (Plate XIII, fig. 21), are only found in pools in the course of hill-streams. The species of *Rasbora* are widely distributed all over India, some of them grow to about 8 inches in length and are considered good for eating. They are, however, surface-feeding forms and have been recorded as enemies of mosquito larvæ. The most widely distributed Indian species of the genus is *R. daniconius* (Plate XIII, fig. 22). The Rasborinæ, as a whole, are rather delicate fishes which prefer clear waters. They can probably be used for mosquito control in the hills where other types of larvivorous fishes are absent. Many genera of the sub-family Cyprininæ are found in Indian waters, but two of these, *Amblypharyngodon* and *Barbus* (*Puntius*), appear to have special value for destroying mosquito larvæ. *Amblypharyngodon* is represented in India by a few species, of which *A. mola* (Plate XIV, fig. 23) is the most widely distributed. It is found throughout India (except perhaps the Malabar Coast), Assam and Burma. Species of *Barbus* (*Puntius*) are many, but only the smaller species, such as *Barbus sophore* (Plate XIV, fig. 24), *B. phutunio* (Plate XIV, fig. 25), *B. ticto* (Plate XIV, fig. 26), etc., etc., are useful in mosquito-control work. These are of a small size, rarely exceeding three inches in length, very hardy and easy to transport. These species are widely distributed all over India, but unfortunately even these small species are greatly

fished for food, particularly in Bengal, Assam, Bihar and Orissa. According to Chaudhuri (*loc. cit.*), *B. phutunio* is one of the most suitable fish for mosquito control, as it is not as delicate as other small species of *Barbus*.

The family Pœcilidæ includes those Cyprinodonts in which a part of the anal fin of the male is modified into an intromittent organ. They differ from most fishes in being viviparous, and produce fresh broods once a month or so for the greater part of the year. The family is confined to the warmer parts of America, and two species of this family of the genera *Lebistes* and *Gambusia* have at different times been introduced into India. The species of the genus *Lebistes* could not be acclimatised in India (*vide supra*, p. 633), but *Gambusia affinis* seems to be flourishing in various hatcheries in different parts of the country. We are informed that persons desirous of using this species for anti-malarial work can get it free of cost from the Ross Field Experimental Station for Malaria, Karnal, Punjab. Deraniyagala (1930) records *Girardinus guppyi* (= *Lebistes reticulatus*), (Plate XV, figs. 29 and 30) as one of the imported larvivorous forms in Ceylon. It may be possible to introduce this species in peninsular India where the climatic conditions are very similar to those of Ceylon, particularly in the hilly areas. *Gambusia affinis* (Plate XV, figs. 27 and 28), the famous top-minnow of Tropical America, has proved very successful as a larvicidal form in anti-malarial campaigns in North America and other countries (International Health Board of the Rockefeller Foundation, 1924). In India it was introduced from Siam about five years ago and is now available in sufficient numbers for anti-malarial work. The conical, fixed teeth in the jaw of *Gambusia* make it a more efficient larvivorous form than *Lebistes* in which the teeth are slender and movable. So far as we are aware, no detailed work has been done in India* on the biology of this species in the field. Nor have any experiments, so far as we are aware, been carried out to test the relative utility of this species as compared with other indigenous fishes, as was done by Dr. B. L. Chaudhuri for the 'Barbados Millions'. The following note by Dr. I. M. Puri of the Malaria Survey of India indicates its great usefulness under laboratory conditions at Karnal :

> 'We had two tanks built, each 8 feet 9 inches × 6 feet × 2 feet 6 inches deep. Early in June this year (1936) I found that they were both breeding anopheline and culicine larvæ in large numbers. Dips were taken with a small enamelled ladle about 3 inches in diameter and 1½ inches deep—the usual white, cup-shaped ladle available in the market—and, on an average, 40 larvæ (mixed) were collected in each dip, along and near the edge. Water at the time was about 2 feet deep, and the species breeding were *A culicifacies, A. stephensi, A. subpictus, Culex fatigans* and *Aëdes albopictus*. I put in twenty *Gambusia* of various sizes, all not full-grown, in each of the tanks and in 24 hours there was not a single larva or pupa in either of the tanks'.

It is very difficult, however, to adjudge the merits of this species under Indian conditions. In large artificial reservoirs where there are no fishes it can probably be used without hesitation, but in waters containing indigenous

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* Dr. K. V. Krishnan of the All-India Institute of Hygiene and Public Health, Calcutta, informs us that some experimental work with *Gambusia* has been carried out by Sweet and Rao in Mysore (*Rec. Mal. Surv. Ind.*, **4**, p. 105) and Timbres in Santiniketan, but no details of the results of the work at Santiniketan have been published so far.

larvivorous species, *Gambusia* should be introduced only after thorough investigations. It may, however, be stated that according to the author of Rockefeller Foundation International Health Board pamphlet, '*Gambusia*, the top-minnow, so successful with the malaria mosquito, is not to be recommended for artificial containers'. For a detailed account of this species reference may be made to the International Health Board pamphlet (1924) and to Fermi's Manual (1935).

Among the freshwater species which cannot be employed successfully for mosquito control are to be included loaches of the families Cobitidæ, Homalopteridæ and Psilorhynchidæ. They feed on insect larvæ and algæ which are found adhering to rocks in the course of the fast currents of mountainous streams. A loach, *Nemachilus beavani*, is figured on Plate IX, fig. 4. Some loaches (species of the genus *Lepidocephalichthys* and a few species of *Botia*) live among debris at the bottom of dirty pools near the base of hills. They are known to come to the surface for breathing purposes when waters become foul during the dry season, but their utility as mosquito-destroyers is very doubtful. Another category of fishes, which is likely to be of little use for mosquito control, consists of eels or eel-like species which live in burrows in mud. Deraniyagala (*loc. cit.*), however, found in Ceylon that the young of the eels of the genus *Anguilla*, such as *A. australis* (Plate IX, fig. 1), feed on mosquito larvæ.

IMPORTANCE OF BIOLOGICAL CONTROL.

The importance of biological control of different pests by their natural enemies, in view of the very valuable work that has been carried out by the Bureau of Entomology of the United States Department of Agriculture and similar departments in Australia, West Indies and other parts of the world, cannot be over-rated. For such measures to be successful it is, however, essential that not only the ecology and biology of the pest should be known in all possible detail, but similar information should also be available in regard to the natural enemy which it is proposed to employ for control work. Unfortunately our knowledge of the ecology and biology of the Indian fishes is very meagre, and this, in our opinion, is the main reason why the results with larvivorous fishes have not been so successful in this country as they have been in America and elsewhere.

Casual reference may also be made to another aspect from which fishes can be useful for mosquito control. It is well known that most mosquito larvæ feed on algæ and other vegetable matter, and further that a number of the smaller species of fish also live on the same type of food. If, therefore, properly selected types of herbivorous fish could be introduced in the likely breeding places of mosquitoes, these fish could help materially in keeping such waters clear of mosquito larvæ owing to very little or no nourishment being available there for the larvæ. We are informed that small species of *Barbus* (*Puntius*) have been found very useful for this purpose in the Dutch East Indies. As has been stated above (*vide supra*, pp. 641 and 642), several Indian species of *Barbus* (*Puntius*) are good mosquito-larvæ destroyers, and as these fishes also feed on algæ, they should prove equally useful in reducing the food of the larvæ. This problem has, so far as we are aware, not been studied in India, and is certainly well worth investigation.

SUGGESTIONS FOR FUTURE WORK.

The lines along which further work is desirable to prove conclusively the part that fish can play as larvicidal agents and to determine the utility of various indigenous species may now be indicated: As a preliminary measure two adjoining areas, one heavily infested with malaria and the other comparatively free from it, should be selected for a survey. An intensive survey of the fish-fauna of the two localities should be undertaken, due regard being paid to any correlation that may exist between the probable density of population of the mosquito larvæ in the different areas of water in the locality and the types of fishes and density of their population in the same pieces of water. Observations should also be made regarding the natural food of the various types of fishes by an examination of their stomach contents. Such data alone would make it possible to elucidate the relative importance of the various species and the rôle they play in the economy of nature. Attention may here be directed to casual observations recorded by several writers regarding the absence of mosquito larvæ in areas of water where certain types of fishes were plentiful, but the value of such observations is greatly discounted by the fact that they were not systematically carried out, and no control observations were made to adjudge the rôle of the supposed larvivorous species. Data are also lacking regarding the numbers of larvivorous fishes necessary for keeping a given area, say an acre of area of water, free from mosquito larvæ. Information in this connection can be collected by constructing a series of small covered tanks, each about a square yard in area, and stocking each with a known number of specimens of a particular species of fish and mosquito larvæ. Daily observations must be made on the larval population of each tank and the reductions in their numbers recorded. A second set of experiments should also be conducted with a similar series of uncovered tanks in areas where mosquitoes normally breed. When the tanks are freshly filled and are free of mosquito larvæ, a definite number of fish, say 1, 2, 3, 4, etc., of a species to be experimented with should be introduced in each tank. Daily observations should be made to see what number of fish is sufficient to keep this area of water free from mosquito larvæ. The experiment can be repeated with different types of fish. The efficacy of various species could thus be tested under experimental conditions, and these observations could then be correlated with others made in the field under natural conditions.

Though our knowledge of the ecological conditions governing fish life in this country is very meagre, a few general observations may be made on the bionomics of the small larvivorous species and the conditions necessary for their existence. Most of the larvivorous species dealt with in this paper live in shallow pools and ditches, or in shallower parts of tanks, *bheels* and marshes. These are precisely the places where mosquito larvæ flourish. In such situations they are subjected to extremes of weather conditions and they appear to have become thoroughly adapted to annual and seasonal changes both in the *milieu* and in their surroundings. Most of them breed in April and May when there are usually a few showers of rain. The young fish pass the hot weather months under very trying conditions, as the ponds and ditches often become almost dry. During the monsoon months, however, they flourish, and growing to the adult size are presumably ready for breeding in October.

The most important requisites for mosquito control by fish to be effective are (*i*) all vegetable matter and débris that may prevent access of fish to

mosquito larvæ should be removed. This means that areas of water to be treated should be kept clean and in as sanitary a condition as possible; (*ii*) all predaceous fishes should, so far as possible, be removed; (*iii*) disconnected pieces of water separated by short distances, such as borrow-pits, etc., should be connected by a regular drainage system so as to enable the fish to wander all over; (*iv*) shallow pits and pools should either be filled up or deepened so that fish may be able to live in them even when the water is at its lowest level in the dry weather; and (*v*) fishing should be strictly prohibited in such areas.

It is also necessary to emphasise that mosquito-control measures by chemicals and by fish cannot go hand in hand. Whereas the former, for large sheets of water, are destructive to all types of animal and probably of most vegetable life, their effect is only of a temporary nature and for such measures to be really effective their application has to be repeated regularly. The control by fishes, if effective, is of a permanent nature and preserves the fauna and flora more or less undisturbed. The use of chemicals is helpful, as we have indicated above, in the case of temporary breeding places of mosquitoes, such as small shallow areas of water, pots, tins, etc., in the vicinity of houses, but in the case of the permanent breeding places biological control alone will probably prove to be the most effective and certainly less expensive in the long run.

Scientific work is becoming more and more complicated day by day owing to an increasing multiplicity of details that are being discovered all over the world. As a result any individual worker's activities are becoming restricted to correspondingly narrower grooves in his particular line of work, if he is to be as conversant with his subject as he should be. The narrower the field of work the more detached becomes the outlook of a worker, and most specialists to-day, to use Holmes' phrase, are nothing more than 'Scarabees'. For all detailed scientific enquiries, therefore, the co-operation of a team of workers is necessary, and this applies more particularly to any investigations in connection with the biological control of mosquitoes by means of their natural enemies, such as fishes. The Zoological Survey of India and its predecessor, the Zoological and Anthropological Section of the Indian Museum, Calcutta, have been helping the malariologists all over the country since 1910 by identifying fishes for them and by advising them about the probable suitability of the various species as larvicides. We again take this opportunity to offer all possible help on behalf of our department to the health authorities all over the country in connection with such work.

Small species of fish from shallow waters can conveniently be collected by means of a small bag-net. The size of the handle can be adjusted according to the requirements of each individual. As soon as the fish are collected they should be transferred to a weak solution of formalin about 2 to 3 per cent (5 to 7 per cent commercial Formaldehyde). The fish die in this solution after dashing about for a couple of minutes and usually at the time of death all the fins become fully expanded, making it possible to count without difficulty the number of rays, etc., which is necessary for proper identification. The fish should be left in this solution for 4 to 5 hours and then preserved in rectified or methylated spirit of wine. If no spirit is available, they may be kept in a biscuit or cigarette tin wrapped up in cotton-wool damped in the weak formalin solution. They can also be despatched conveniently by post in such

small tins and there is very little risk of damage if they are properly packed inside the tin. Labels giving localities and other particulars about habitat, etc., should be placed with collections from various areas, and the fish from different collections should be rolled up in separate pieces of muslin or gauze before they are packed in a tin with damp cotton-wool. This method is much more convenient and economical than sending specimens in liquid preservatives in glass tubes.

It is of paramount importance to make notes of the habits and habitats of the various species collected, and if the fishes cannot be determined in the field, they should be distinguished by suitable numerals or letters. Among the ecological conditions regarding which information is desirable are :—(*i*) nature of substratum, such as sandy, rocky, etc.; (*ii*) nature of water—stationary, slow or fast running, shallow, deep, dirty, clear, foul-smelling, etc.; (*iii*) nature and extent of vegetation; and (*iv*) animal associations or notes regarding other aquatic animals living in the same piece of water. Notes on habits should be taken under the following headings, which were tabulated by Mr. W. P. Seal, formerly of the United States Bureau of Fisheries, in the form of questions :—

'(1) Do they live in quiet or open water ?
(2) Do they swim amid aquatic and semi-aquatic vegetation ?
(3) Are they solitary or gregarious ?
(4) Are they sluggish, lethargic, or active ?
(5) Are they carnivorous, herbivorous, or omnivorous ?
(6) Are they bottom-feeders, top-feeders, current-feeders, or variable ?
(7) Are they destructive of other fish ?
(8) Are they found where there are mosquitoes ?'

It may also be noted that most of the indigenous larvivorous fishes, more particularly of South India, are available from the Madras Fisheries Department from its Fish Farms at a nominal cost. Specimens of *Gambusia affinis* are, as indicated already (*supra*, p. 642), available from the experimental station of the Malaria Survey of India at Karnal.

It is unfortunate that there are no definite sources of supply in other provinces of India, but probably the Fisheries departments in the different provinces could be prevailed upon to arrange for supplies of such species to areas within their provinces. The Madras Fisheries Department has designed suitable containers for the transport of fish and also published detailed instructions for the care and handling of the fish during transport as a result of several years' work. These instructions in general would apply all over India, and it is not necessary, therefore, to deal with this question here.

In conclusion we would emphasise the far-reaching nature of the resolution regarding larvivorous fish passed by the Imperial Malaria Conference held at Simla in October **1909** (*supra*, p. 634). It is as pertinent to-day as it was a little over a quarter of a century ago when it was adopted. Its scope is fully comprehensive and so long as the enquiry envisaged in this resolution is not carried out, even the most useful indigenous species can at best be designated as probably larvicidal fishes.

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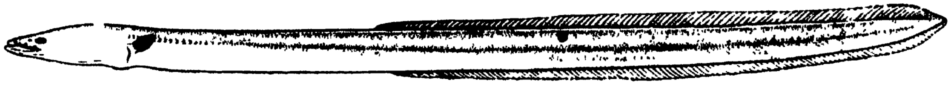
PLATE IX.



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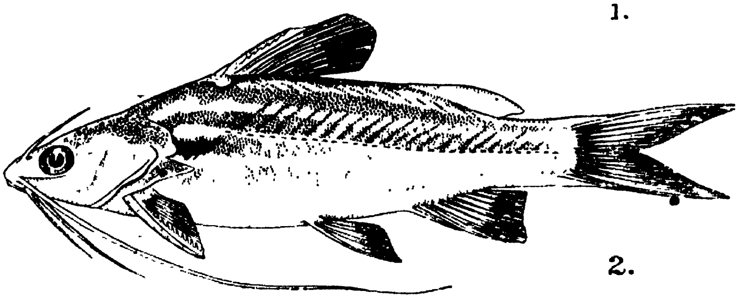

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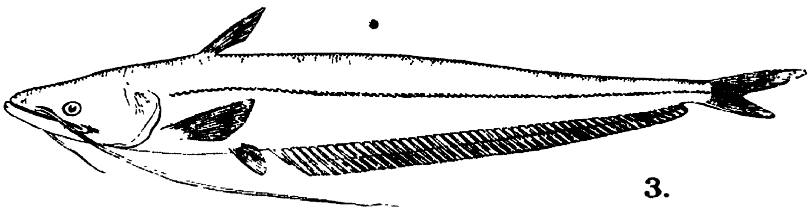

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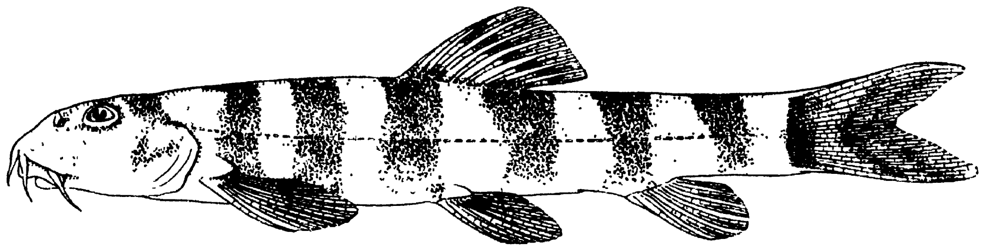

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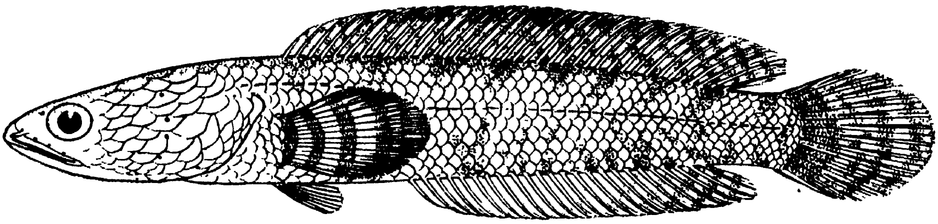
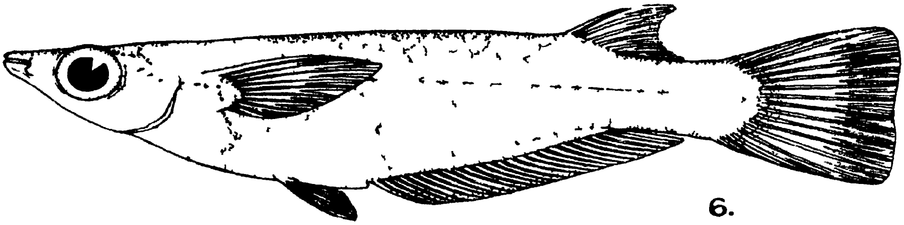


5.

Fig. 1. *Anguilla australis* Richardson. Young. × 1½.
„ 2. *Mystus tengara* (Hamilton). Young. × 1⅛.
„ 3. *Wallago attu* (Bl. & Schn.). Young. × ⅜.
„ 4. *Nemachilus beavani* Günther. × 2¼.
„ 5. *Ophicephalus gachua* Hamilton. Young. × 1

Plate X.



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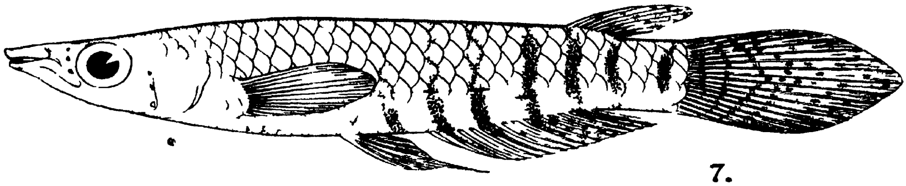

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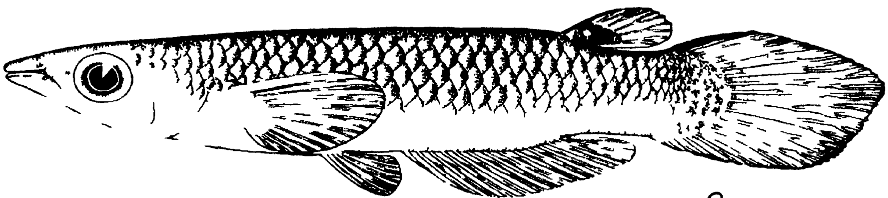

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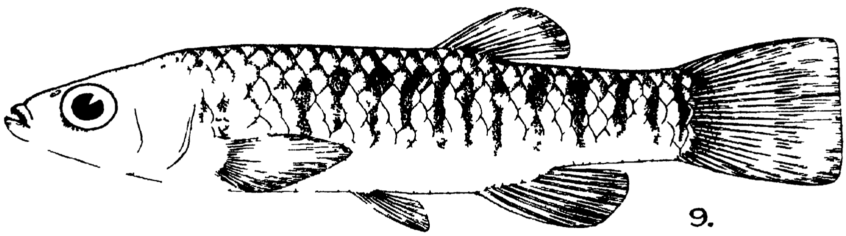

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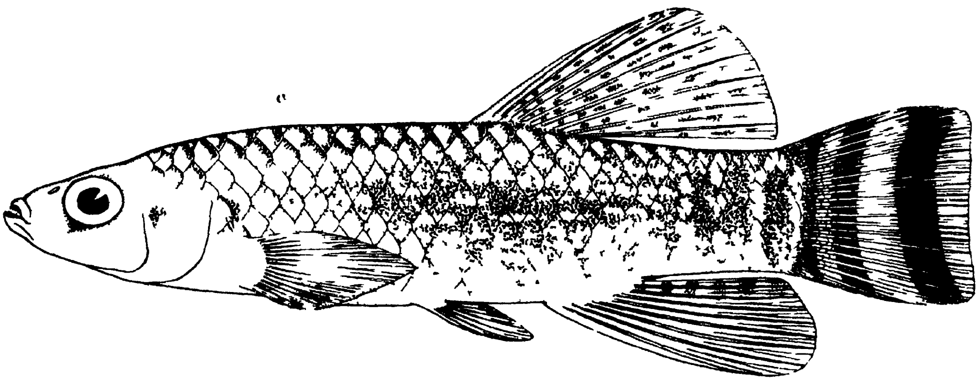

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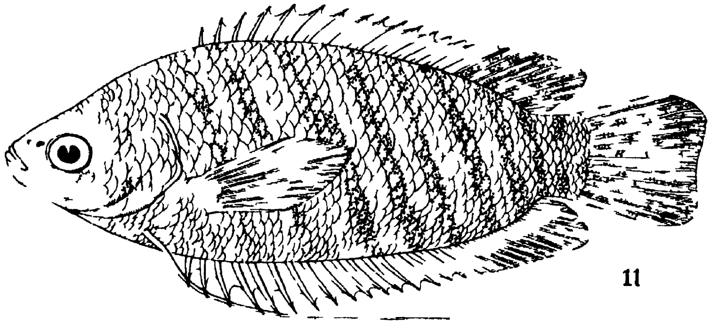
Fig. 6. *Aplocheilus melastigma* McClelland. × 2½.
" 7. *Panchax lineatus* (Cuvier and Valenciennes). × 2½
" 8. *Panchax panchax* (Hamilton). × 2½.
" 9. *Lebias dispar* Ruppell ♀. × 2½.
" 10. *Lebias dispar* Rüppell. ♂. × 2½

PLATE XI



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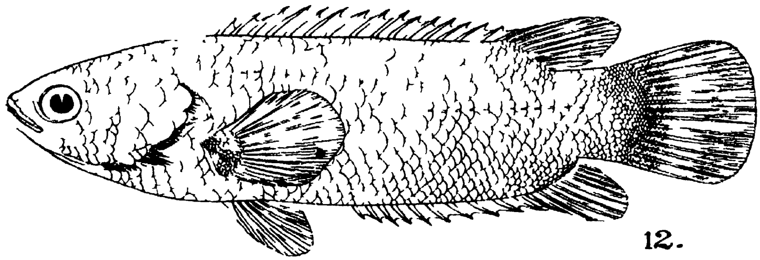
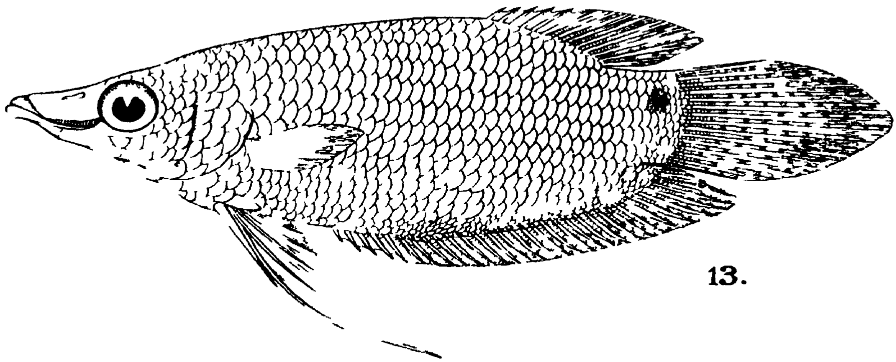


12.



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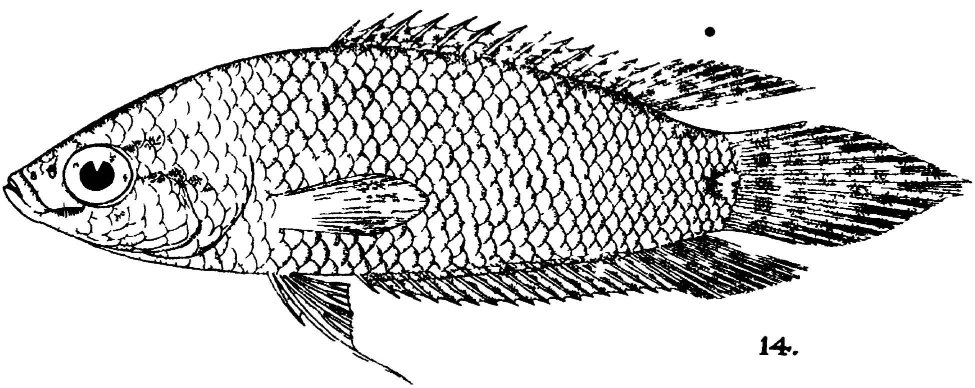
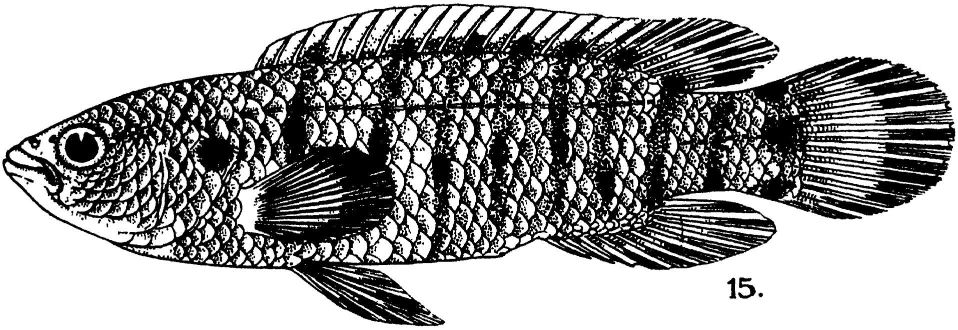


14.

Fig. 11. *Colisa fasciata* (Bloch and Schneider) × [illegible].
„ 12. *Anabas testudineus* (Bloch) × [illegible].
„ 13. *Ctenops nobilis* McClelland × 1[illegible].
„ 14. *Macropodus cupanus* Cuvier and Valenciennes × 3[illegible].

Plate XII.



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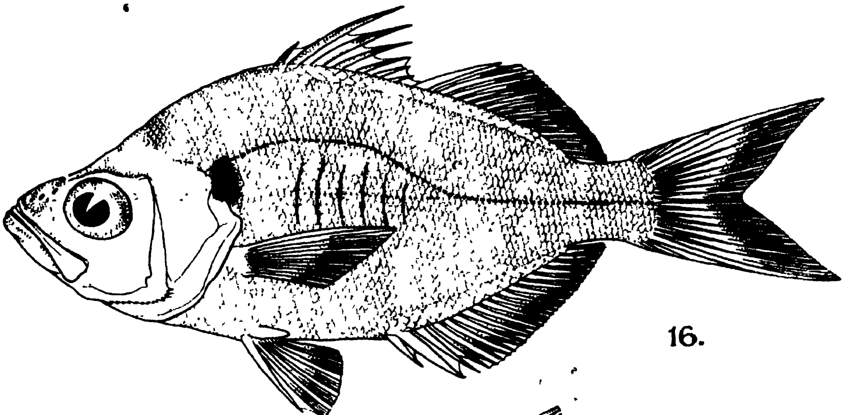

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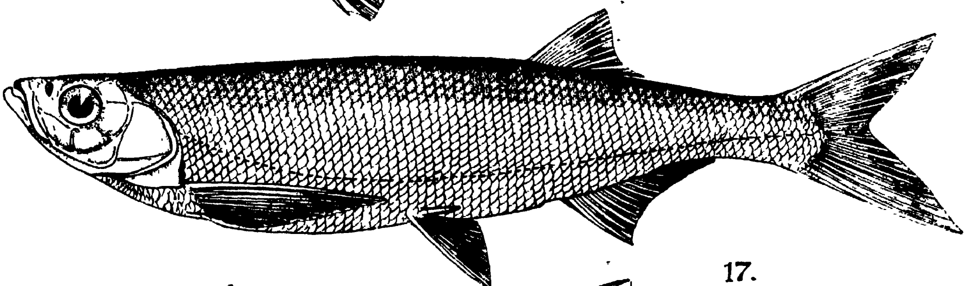

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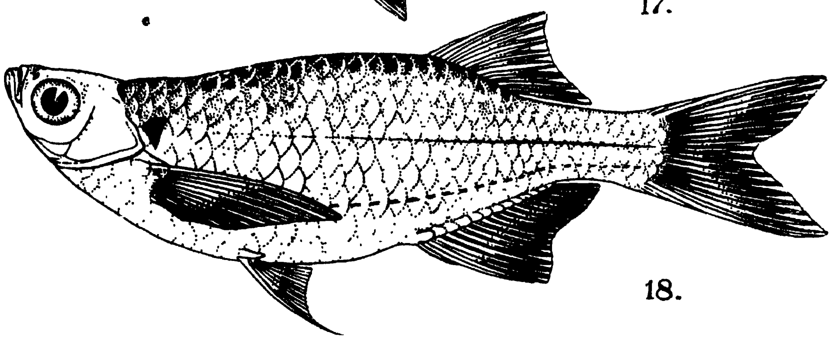
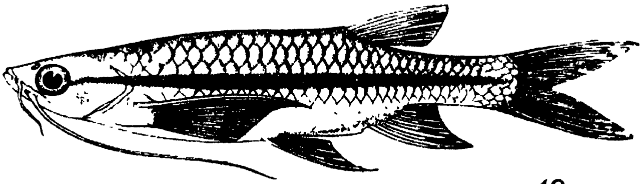


18.

Fig. 15. *Badis badis* (Hamilton). $\times 1\frac{1}{2}$.
„ 16. *Ambassis ranga* (Hamilton). $\times 1\frac{1}{8}$.
„ 17. *Chela bacaila* (Hamilton). $\times \frac{3}{4}$.
„ 18. *Laubuca laubuca* (Hamilton). $\times 2$.

PLATE XIII.



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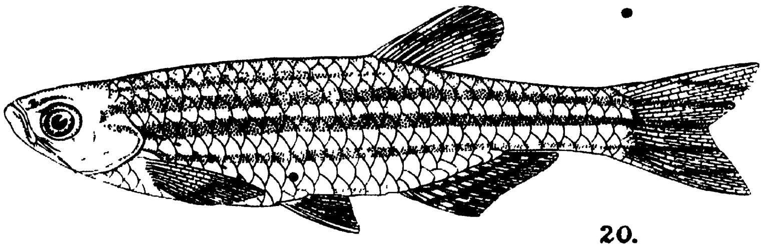

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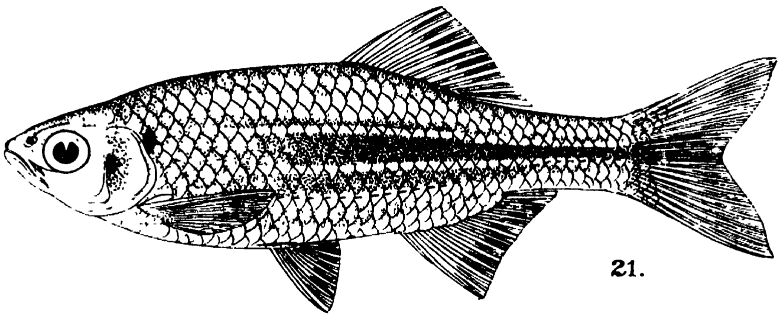

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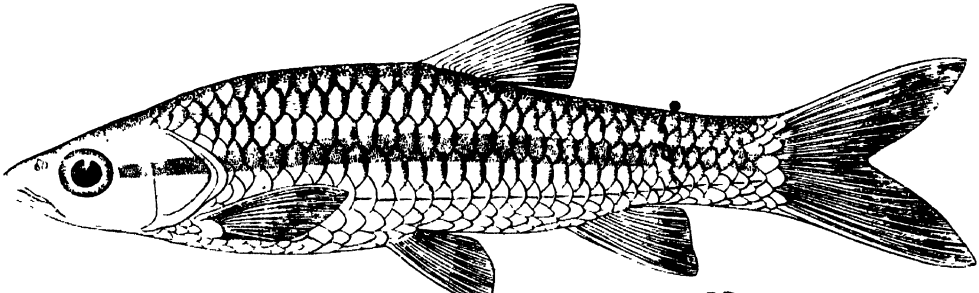
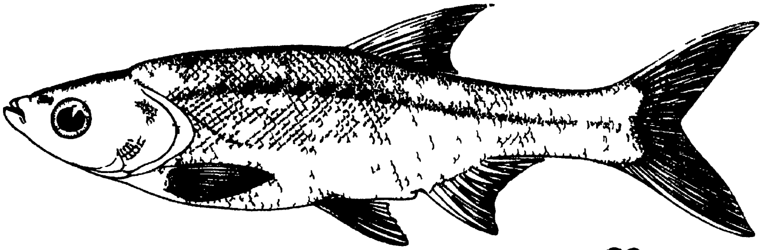


22.

Fig. 19. *Esomus danricus* (Hamilton). × 1½.
„ 20. *Brachydanio rerio* (Hamilton). × 3¾.
„ 21. *Danio aequipinnatus* McClelland. × 1½.
„ 22. *Rasbora daniconius* (Hamilton). × 1½.

PLATE XIV.



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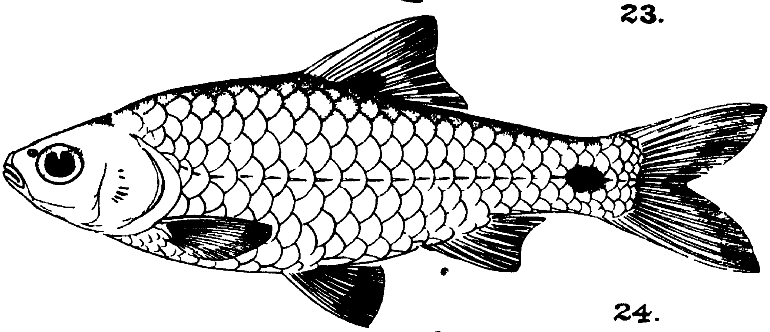

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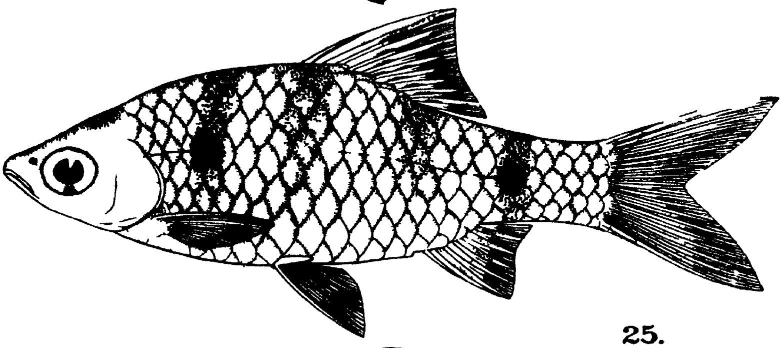

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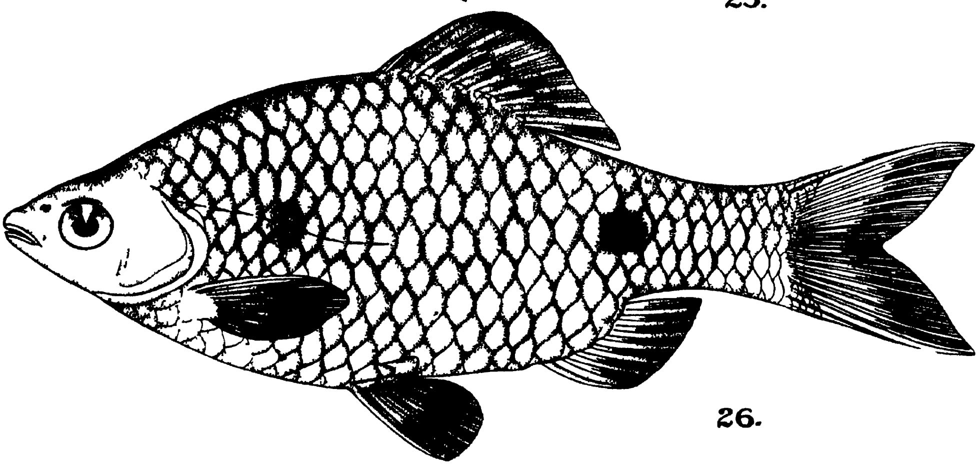
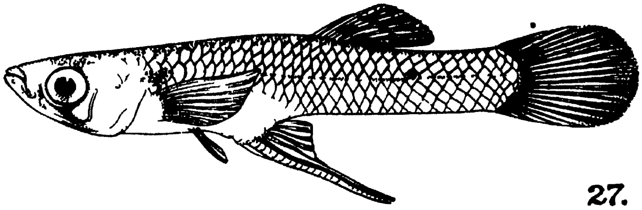


26.

Fig 23 *Amblypharyngodon mola* (Hamilton) $\times 1\frac{1}{8}$
" 24 *Barbus* (*Puntius*) *sophore* (Hamilton) $\times 1\frac{1}{8}$
" 25 *Barbus* (*Puntius*) *phutunio* (Hamilton) $\times 2\frac{1}{4}$
" 26 *Barbus* (*Puntius*) *ticto* (Hamilton) $\times 1\frac{1}{8}$

PLATE XV.



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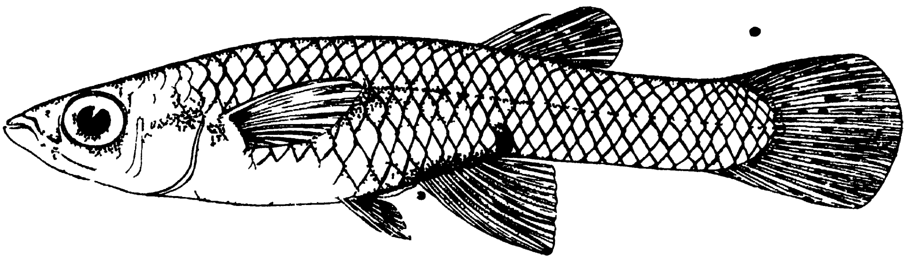

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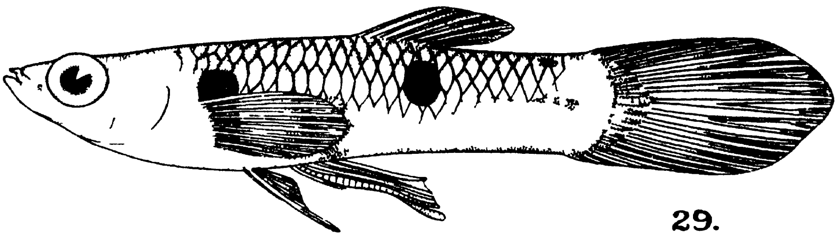

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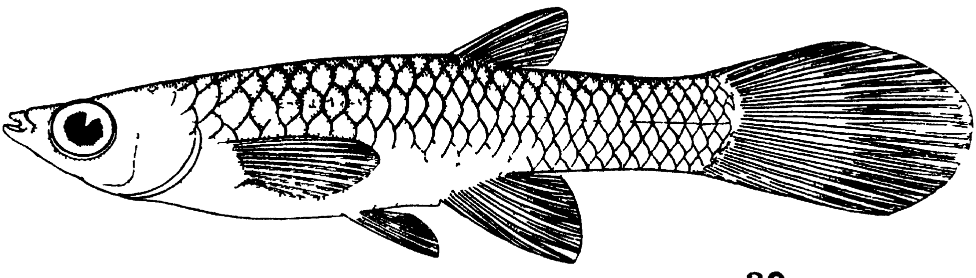

30.

Fig 27. *Gambusia affinis* (Baird and Girard). ♂. × $2\frac{2}{3}$.
" 28. *Gambusia affinis* (Baird and Girard) ♀. × $2\frac{2}{3}$.
" 29. *Lebistes reticulatus* (Peters) ♂. × $4\frac{1}{5}$.
" 30 *Lebistes reticulatus* (Peters). ♀. × $4\frac{1}{5}$.

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ABSTRACT.

A BRIEF REPORT ON THE MOSQUITO CONTROL WORK IN VIZAGAPATAM PORT*.

BY

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(MS. 5 pp. with one Sketch Map.)

[1st September, 1936.]

INTENSIVE anti-larval and anti-mosquito measures have been carried out in and around Vizagapatam Port since 1928, but in view of the growing importance of *Aëdes aegypti* in Indian ports special observations were made on *Aëdes* fauna of this locality since December 1935. Three species of *Aëdes* were found breeding in this area, *Aëdes aegypti, Aëdes albopictus* and *Aëdes vittatus.*

All types of actual and potential breeding places of these mosquitoes were examined once a week by a special staff consisting of one trained inspector, and two coolies (total expense: Rs. 72-8-0) and dealt with suitably. A number of catching stations were established in the industrial area of the Port and during the period from 8th December, 1935 to 30th June, 1936, 182 mosquitoes were collected from them. Of these only 19, i.e., 10.4 per cent, were *Aëdes.*

Almost every ship visiting the Port was examined for mosquito larvæ and adults but in only one of them, s.s. *Ortri,* one pupa of *Aëdes aegypti* and ten adult culicines other than *Aëdes* were found (8th December, 1935).

* Copy of the original manuscript has been placed in the Library of the Malaria Survey of India, Kasauli. This is available on loan to workers who wish to consult the original. (*Editor*).

A study was made of the algal flora of 17 different collections of water in which anopheline larvæ of different species were found breeding. *Spirogyra* was the predominating alga in most of the breeding places, *Chlamydomonas* being the next commonest.

About 20 *Gambusia* fish were put in a well in which *A. culicifacies* and *A. stephensi* had been found breeding heavily and which was inaccessible for ordinary anti-larval measures. These fish proved very successful and apparently flourished in the well.

R. C. WATS.

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